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Silvicultural Systems and Cutting Methods for Old-Growth Lodgepole Pine Forests in the Central Rocky Mountains

Robert R. Alexander

Abstract

Guidelines are provided to help forest managers and silviculturists develop even- and uneven-aged cutting practices needed to convert pure and mixed old-growth lodgepole pine forests into managed stands. Guidelines consider stand conditions, succession, windfall risk, and insect and disease susceptibility. Cutting practices—clearcutting, shelterwood, and selection—are designed to integrate timber production with increased water yield, maintained water quality, improved wildlife habitat, and enhanced opportunities for recreation and scenic beauty.

Silvicultural Systems and Cutting Methods for Old-Growth Lodgepole Pine Forests in the Central Rocky Mountains

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Lodgepole pine (*Pinus contorta* Dougl. ex Loud.) forests (SAF Type 218) (Pfister and McDonald 1980) are second in multiple-use importance only to Engelmann spruce (*Picea engelmannii* Parry ex Engelm.)—subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) forests in the central Rocky Mountains. These forests occupy about 3.2 million acres of timberland, with an estimated 18 billion board feet (INT 1/4 Rule) of sawtimber in Colorado and Wyoming (Green and Van Hooser 1983). They grow on areas where timber production potential varies from high to very low. These forests also provide watershed protection, streamflow, habitat for wildlife, forage for livestock, recreational opportunities, and scenic beauty. Many areas now occupied by lodgepole pine have the potential for growing Engelmann spruce and subalpine fir or Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* (Beissn.) Franco) (Alexander 1974, Alexander et al. 1983).

NATURAL STANDS

AGE-CLASS DISTRIBUTION

About one-half (47%) of the stocked natural lodgepole pine area is in sawtimber stands. Much of these stands are overmature and declining in general vigor and soundness (Alexander 1974, Green and Van Hooser 1983).

Thirty-eight percent of the lodgepole pine is in poletimber stands; but much of the poletimber is either overmature, overly dense, or growing on sites not likely to produce a sawlog-sized tree. Most of these stands became established after wildfires burned between the late 1800s and the early 1900s. Because wildfires are random events, poletimber stands are abundant in some areas and rare in others. About 12% of the lodgepole pine forests in the central Rocky Mountains are classified as seedling and sapling stands that originated after either fire or timber harvest. Many of these stands are overly dense and require thinning to reduce stocking. Only about 3% of the lodgepole pine timberland is classified as nonstocked. Failure of tree reproduction after clearcutting large areas where the nonserotinous cone habit is prevalent accounts for some of the nonstocked area; but not all nonstocked lands now classified as commercial can support lodgepole pine forests (Alexander 1974, Green and Van Hooser 1983).

REACTION TO COMPETITION

Lodgepole pine is rated shade-intolerant (Baker 1949). It is comparable in shade tolerance to ponderosa pine,

but is more intolerant than associates such as Rocky Mountain Douglas-fir, blue spruce (*Picea pungens* Engelm.), Engelmann spruce, and subalpine fir. However, it is not as intolerant as aspen (*Populus tremuloides* Michx.), another common associate.

Lodgepole pine is an aggressive pioneer and invader whose occurrence is largely a result of fire (Clements 1910, Lotan and Critchfield 1985, Stahelin 1943). Its successional status depends upon environmental conditions, history, and competition from associated species. Lodgepole pine is seral when it is a temporary occupant of the site. It is a minor seral where it is an overstory component of stands with a mixed composition and will be replaced in 50 to 100 years by more tolerant associates. Lodgepole pine is a dominant seral where it is an overstory with a vigorous understory of shade-tolerant associates. Replacement usually requires 100 to 200 years; but if mountain pine beetles (*Dendroctonus ponderosae* Hopk.) attack these stands and remove the larger pines, the time required for climax species to occupy the site is shortened. It is a persistent seral where stands are the result of catastrophic fires; and some areas have burned so often and so extensively that large acreages are nearly pure pine. In those situations, lodgepole pine is maintained on the area, because there is no seed source for the normal climax species. Lodgepole pine is a climax in those situations where it is held on the site by natural or artificial means, and therefore, is self-perpetuating (fig. 1) (Lotan and Critchfield 1985, Pfister and Daubenmire 1975). One example of a naturally stable lodgepole pine community is at lower elevations along the east slope of the Front Range, in northern Colorado. Douglas-fir, considered the climax species, no longer reproduces itself in stands dominated by lodgepole pine, because the sites have become too dry (Moir 1969).
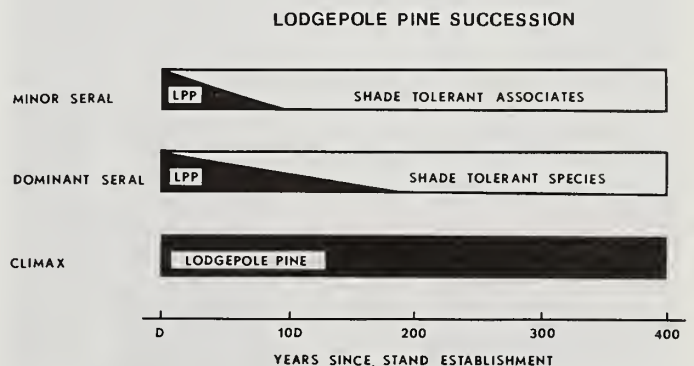

Figure 1.—Successional status of lodgepole pine.

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STAND CONDITIONS

The lodgepole pine type is generally regarded as an even-aged, single-storied forest, varying in age from place to place but uniform in age within any given stand. This is true only where favorable fire, seed, and climatic conditions once combined to produce many seedlings at one time (Lexen 1949). Sometimes, under these conditions, lodgepole pine develops into overly dense, stagnated stands (fig. 2). Elsewhere, lodgepole pine grows on a wide range of sites with a great diversity of stand conditions. It can occur as two-aged, single- or two-storied stands; three-aged, two- or three-storied stands; and even-aged to broad-aged multi-storied stands (Tackle 1955). Spacing of these stands ranges from dense to open. Multi-storied stands, and to a lesser extent, two- and three-storied stands, generally originated from either scattered trees that produced seed for subsequent stand development, or the gradual deterioration of old-growth stands resulting from wind, insects, and diseases (Alexander 1975).

Lodgepole pine stands frequently are pure pine over much of the area occupied, especially where stands originated after repeated fires and there is no seed source for other species (Lotan and Critchfield 1985, Tackle 1961). However, mixed stands of lodgepole pine and other species are not uncommon, especially lodgepole pine, Engelmann spruce and subalpine fir, and lodgepole pine and Douglas-fir. In pure stands of lodgepole pine of medium to high density, there seldom is an understory of reproduction; in low-density stands there may be younger trees in the understory. If this advanced growth has not been suppressed for a long time, it will respond to release.

In mixed stands, the overstory either can be pure pine, or pine, spruce and/or fir at higher elevations, and pine and Douglas-fir at lower elevations, with the climax species in the understory. Advanced growth of the climax species will respond to release when the overstory is removed (Alexander 1975).

Figure 2.—Overly dense stagnated stand of lodgepole pine.

DAMAGING AGENTS

WIND

In the central Rocky Mountains, lodgepole pine is generally considered susceptible to windthrow after cutting. Partial cutting increases the risk, because the entire stand is opened up and, therefore, vulnerable. Less damage is associated with clearcutting, because only the boundaries between cut and uncut areas are vulnerable (Alexander 1966, 1975; Mason 1915b). While the tendency to windthrow is frequently attributed to a shallow root system, the development of the root system varies with soil and stand conditions. On deep, well-drained soils, trees have a better root system than on shallow or poorly drained soils. With the same soil conditions, individual stems in denser stands are less windfirm, because trees that have developed together in dense stands over long periods of time mutually protect and support each other and do not have the roots, boles, and crowns to withstand exposure to the wind if they are opened up drastically. The risk of blowdown is also greater in stands with defective roots and boles. The presence of old windfalls is a good indication of lack of windfirmness. Furthermore, regardless of how stands are cut or the soil and stand conditions, the risk of blowdown is greater on some exposures than others. The following windfall risk situations based on exposure have been identified (fig. 3) by Mason (1915b) and Alexander (1964, 1967, 1975).
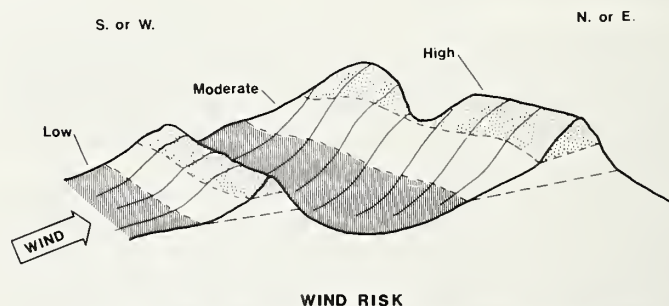
WIND RISK

Figure 3.—Wind risk in relation to topographic exposure.

Low
1. Valley bottoms except where parallel to the prevailing winds, and all flat areas.
2. All lower and gentle middle north- and east-facing slopes.
3. All lower and gentle middle south- and west-facing slopes that are protected by considerably higher ground not far to windward.

Moderate
1. Valley bottoms parallel to the direction of prevailing winds.
2. All lower and gentle middle south- and west-facing slopes not protected to the windward.
3. Moderate to steep middle and all upper north- and east-facing slopes.
4. Moderate to steep middle south- and west-facing slopes protected by considerably higher ground not far to windward.

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High
1. Ridgetops.
2. Moderate to steep middle south- and west-facing slopes not protected to the windward, and all upper south- and west-facing slopes.
3. Saddles in ridgetops.

The risk of windfall in these situations is increased at least one category by factors such as poor drainage, shallow soils, and defective roots and boles. All situations become high risk if the stands are exposed to special topographic situations such as valley bottoms with steep side slopes that are parallel to the wind and become narrower in the direction that the wind blows (fig. 4), and gaps and saddles in ridges at higher elevations to the windward that can funnel wind into the area (fig. 5).

INSECTS

Bark Beetles

Many species of insects infest lodgepole pine (Keen 1952); but the mountain pine beetle is the most serious pest in mature to overmature lodgepole pine stands in the Rocky Mountains (Amman 1978). Epidemics have occurred throughout recorded history (Roe and Amman 1970), and severe outbreaks have occurred in Wyoming and northern Colorado (fig. 6), where several old-growth

Figure 4.—Very high wind risk; valley bottoms parallel to the direction of the wind.

Figure 5.—Very high wind risk; winds funneled through saddle in a ridgetop.

Figure 6.—Lodgepole pine attacked by mountain pine beetles.

stands that were protected from wildfires reached a high degree of susceptibility to attack (Alexander 1975).

Adult beetles attack lodgepole pine in July and August, introducing blue-stain fungi that hastens the death of the tree (Amman 1978). Beetles create egg galleries, mate, and deposit eggs in the phloem layer. Larvae then feed on the phloem and, in conjunction with blue-stain fungi, girdle and kill the tree. The first indications of attack are pitch tubes on the trunk where beetles have entered, and boring dust in the bark crevices and around the base of the tree. Trees attacked in the summer usually begin to fade the following spring. Needles change from green to yellow green, sorrel, and finally rusty brown before dropping off (McCambridge and Trostle 1972).

Not all stands are equally susceptible to attack. Epidemic outbreaks are usually associated with stands that contain (1) at least some vigorous medium- to thick-phloemed trees 14 inches in diameter and larger, (2) trees more than 80 years old, (3) trees with mean diameters larger than 8 inches, and (4) trees growing at elevations where temperatures are favorable to brood development (Amman 1978). As the larger trees are killed, the beetles attack smaller diameter trees until the outbreak finally subsides, because the phloem of these trees is not thick enough to provide a food supply. Trees smaller than 6 inches d.b.h. are rarely killed (Cole and Amman 1969). Although natural factors such as a sudden lowering of fall temperature or prolonged subzero winter temperatures, nematodes, woodpeckers, or parasites may reduce populations, they cannot be relied upon to control outbreaks (McCambridge and Trostle 1972).

Another potentially destructive bark beetle is the pine engraver (*Ips pini* Say.). Pine engraver populations commonly develop in logging slash, especially if it is shaded or does not dry quickly for some other reason. The most effective control is removing or burning large slash and exposing small slash to direct sunlight and wind so that it dries rapidly (Sartwell et al. 1971).

Other Insects

Other insects generally do not cause widespread losses but can be locally serious. These include the pandora moth (*Coloradia pandora* Blake) and the lodgepole pine
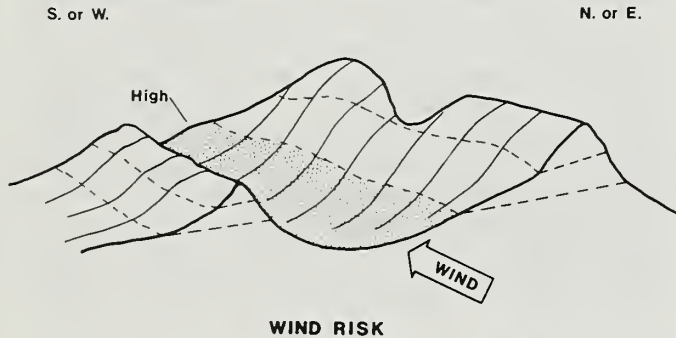
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terminal weevil (*Pissodes terminalis* Hopping) that produce distorted or forked crowns in young stands (Furniss and Carolin 1977).

DISEASES

Dwarf Mistletoe

Dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.) is the most serious disease affecting lodgepole pine (Hawksworth 1965) (fig. 7). Surveys in Colorado and Wyoming show that about 50% of the commercial lodgepole pine forests are infected to some degree by dwarf mistletoe (Johnson et al. 1981). Infection in two Wyoming forests was greater than 60%. Dwarf mistletoe reduces growth, increases mortality (Hawksworth and Hinds 1964), and drastically reduces seed production. The mortality rate depends largely on the age of the host tree when attacked. Young trees die quickly, while older trees with well-developed and vigorous crowns may not show appreciable effects for years. Dwarf mistletoe is most damaging in stands that have been partially opened up by cutting, mountain pine beetles, or windfall, and is least damaging on areas regenerated after catastrophic fires (Hawksworth and Dooling 1984). Heavily infected old-growth stands frequently have only about 50% of the sawtimber volume of comparable uninfected stands (Hawksworth and Dooling 1984).

Dwarf mistletoe is a parasitic plant that flowers in April and May. At maturity (August and September), fruits are forcibly ejected for distances up to 30 feet, and in one study, about 40% of seeds produced were intercepted by trees (Hawksworth 1965). Seeds are covered with a gelatinous material, which acts as a lubricant when wet from rain and facilitates movement from pine needles onto branches where infection takes place (Hawksworth 1975). Rate of spread of mistletoe is slow—about 1.5 feet per year in open stands and 0.9 foot per year in dense, immature stands (Hawksworth and Dooling 1984, Hawksworth and Graham 1963).

The disease is difficult to detect in recently infected stands, because trees show no abnormalities except for the inconspicuous shoots on branches and main stems. Where the parasite has been present for a long time, stands have one or more heavily damaged centers characterized by many trees with witches' brooms, spike-tops, and an above-average number of snags with remnants of brooms (Hawksworth and Dooling 1984).

Although optimum development is favored by a vigorous host, and the most vigorous trees are most heavily infected, frequency of infection is usually higher on poor than good sites. Furthermore, where site index is 70 or greater (Alexander et al. 1967), only the middle and lower crowns of dominants and codominants are susceptible to heavy infection, while trees in the intermediate or lower crown classes are susceptible to heavy infection throughout their crowns. Where the site index is below 70, all crown classes are susceptible to heavy infection throughout the crowns. In Colorado and Wyoming, dwarf mistletoe has an altitudinal limit of about 300 to 500 feet below the upper limit of commercial lodgepole pine forests. This means that in some areas, considerable lodgepole pine is above the dwarf mistletoe zone (Hawksworth and Dooling 1984).

To quantify the severity of infection, Hawksworth (1961, 1977) developed the 6-class mistletoe rating system (fig. 8). The average stand rating can be estimated by determining the percentage of tree infection in the stand.
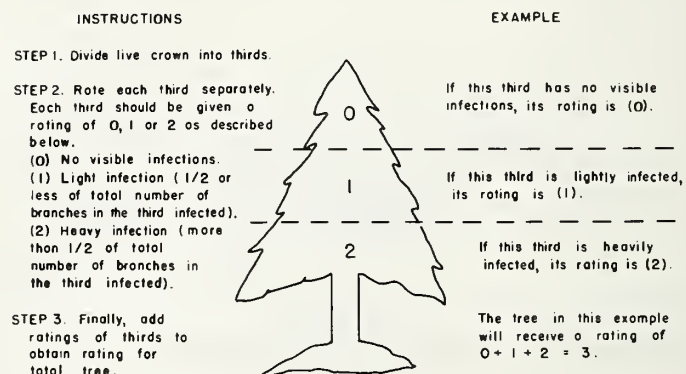
Figure 8.—The six-class mistletoe rating system.

Average stand mistletoe rating	Percent of trees infected
1	50
2	70
3	90
4	97
5	99
6	100

Rust Fungi

Comandra blister rust, a canker disease caused by *Cronartium comandrae* Pk., commonly occurs in the central Rocky Mountains; but damage has been most extensive

Figure 7.—Lodgepole pine infested with dwarf mistletoe.

in northern Wyoming (Geils and Jacobi 1984, Peterson 1962). Girdling causes dead tops and flagging branches, which are the most conspicuous symptoms until dead trees begin to appear. On larger stem infections, cankers with an abundance of yellow, dried resin are a conspicuous symptom (Mielke et al. 1968). The disease cannot pass directly from pine to pine; it requires an intermediate host (*Comandra umbellata* (L.) Nutt.).

The damage from Comandra rust usually is not spectacular; but trees of all sizes and ages are susceptible (Peterson 1962). Seedlings may be killed in a relatively short time. In older trees, the time between initial infection and death may be 25 or more years, because the infection enters the trunk through the branches, and the rate of spread is slow. Under conditions favorable to the rust, stands may be heavily damaged over limited areas. In those stands, 50% or more of the living and dead trees have cankers, and about 50% the cankered trees have spike-tops (Geils and Jacobi 1984, Krebill 1965). However, the infection usually is lighter and scattered through the stand (Peterson 1962).

Sanitation salvage cutting is about the only practical way of controlling the disease in forest stands (Mielke et al. 1968). In areas of high tree values, it may be possible to prune infected branches from lightly infected trees; but heavily infected trees should be cut.

Western gall rust (*Peridermium harknessii* Moore) occurs on lodgepole pine throughout the Rocky Mountains, but is not as distinctive as Comandra rust, because most infections occur as galls on branches rather than on the trunk. However, when stem infections occur, they usually result in hip cankers. Trees frequently are broken off by the wind at the point of infection. Mortality in the seedling stage, loss of growth, and cull are the principal forms of damage from this rust. Removal of infected trees in silvicultural operations is the only practical way to control gall rust damage in forests. Presence of a few galls is not sufficient cause to remove a tree. Only cankered trees need be cut (Peterson 1960).

Other Diseases

The major root and butt fungi attacking lodgepole pine in the Rocky Mountains are *Polyporus circinatus* Fr., *Coniophora puteana* (Schum:Fr.) Karst, and *Armillaria mellea* (Vahl.:Fr.) Quel.; the principal trunk rot fungus is *Phellinus pini* (Thore:Fr.) Karst (= *Fomes pini* (Thore:Fr.) Lloyd) [(Fr.) Karst)] (Hepting 1971, Hornibrook 1950).

As old-growth is converted to managed stands, decay fungi can be expected to decrease. Early removal of lodgepole pine with known indicators of defect will help establish healthy, vigorous forests with greater growth potential. Rot losses in future stands can be minimized by shorter cutting rotations, such as 120 years or less. Close supervision of logging operations to reduce mechanical injuries will minimize courts of entry for decay fungi. Proper slash disposal will lower inoculum potential of rot fungi in residual stands. These sanitation measures are important because direct control of rots is seldom feasible or economical.

FIRE

Fire has had a profound effect on the structure and composition of lodgepole pine forests. Succession to "climax" species is frequently interrupted by fire. As a result of fire, lodgepole pine often exists in extensive, pure stands, because there is little or no seed source of associated tree species. Thus, replacement of lodgepole pine is slow. The effects of fire, fuel accumulation, stand development, and insects and diseases in lodgepole pine are all part of a set of complex biological and physical relationships that control the establishment and maintenance of stands (Lotan and Perry 1983).

The effect of fire on the structure and composition of a lodgepole pine stand depends greatly on its intensity. Fires in lodgepole pine vary from surface fires of low intensity to crown fires of high intensity. High-intensity fires destroy the residual stand and may result in a heavy seeding from serotinous cones. If the old stand contains enough trees with serotinous cones, a dense, even-aged, young stand usually results. Occasionally, fires may be intense enough to destroy cones, resulting in a thinly stocked stand. Low-intensity surface fires may kill advanced reproduction of other species, but leave at least some residual lodgepole pine, which results in an uneven-aged stand. Fire frequency may vary from 20 to 500 years (Lotan and Perry 1983).

ANIMALS

Animals rarely damage established lodgepole pine. Mule deer (*Odocoileus hemionus* Rafinesque) and elk (*Cervus elaphus* L.), when yarded up in the winter, may browse lodgepole pine, but only as a last resort. Bears (*Ursus* spp.) and procupines (*Erethizon dorsatum* Brandt) occur in lodgepole pine forests but seldom damage trees, except locally.

CUTTING HISTORY

The first cuttings in lodgepole pine forests occurred in the late 1800s. Some of the earliest were clearcuttings to provide stulls, lagging, and charcoal for mining operations. Pioneer ranchers used lodgepole pine for fuel, fences, and corrals. Later, millions of cross ties were hewn for the railroads. Following World War I, a form of partial cutting became standard practice on the national forests of the central Rocky Mountains, even though early studies suggested that clearcutting satisfied the silvical requirements of the species (Bates et al. 1929, Clements 1910, Mason 1915a). The usual practice was to mark stands for the selective removal of special products such as ties, posts, poles, and sawlogs. Cutting often was heavy, because everything salable usually was marked for removal. Most skidding was done with horses. Seedbed preparation was limited to the disturbance associated with logging and slash disposal. Slash either was lopped and scattered or piled and burned (Thompson 1929).

Generally, partial cutting, especially when more than 50% of the total basal area was removed, was not a successful means of arresting deterioration in old-growth stands or accelerating growth of the residual stand. For example, residual trees on the Fraser Experimental Forest suffered heavy mortality when about 60% of the total basal area was removed by either individual tree selection or modified seed-tree cutting (Alexander 1966b) (fig. 9). Furthermore, net increment was less than in uncut stands. Similar results followed heavy partial cutting elsewhere in the central Rocky Mountains, and in the northern and Canadian Rockies (Blyth 1957, Hatch 1967, LeBarron 1952). Even where mortality was not a serious problem, heavy partial cutting often left the older, decadent stands in such poor condition that not only was there little or no growing stock available for another cut, but the stands had little appearance of permanent forest cover (Tackle 1965).

Where substantial reserve volumes were left, partial cutting was successful in some instances in the sense that the residual stand did not blow down. On the Fraser Experimental Forest, windfall losses were light and other mortality was negligible after partial cutting removed about 45% of the total basal area in old-growth lodgepole pine stands by a modified shelterwood cut, even though the stands were exposed to windstorms that nearly destroyed adjacent, partially cut stands where 60% of the total basal area was removed (Alexander 1966b). Net increment was no greater than in uncut stands, however.

There are numerous examples of early cuttings on many national forests in Colorado and Wyoming, where a light to moderate shelterwood cut that removed 30% to 40% of the total basal area did not result to excessive mortality. The openings created have regenerated to either new lodgepole pine or the climax species—Engelmann spruce and subalpine fir. Where dwarf mistletoe infection in overstory trees was light, the new pine stand was not heavily infected (Alexander 1975).

In 1939, Taylor developed a tree classification scheme for marking lodgepole pine for partial cutting that is still useful (fig. 10). He based his classification on the area,
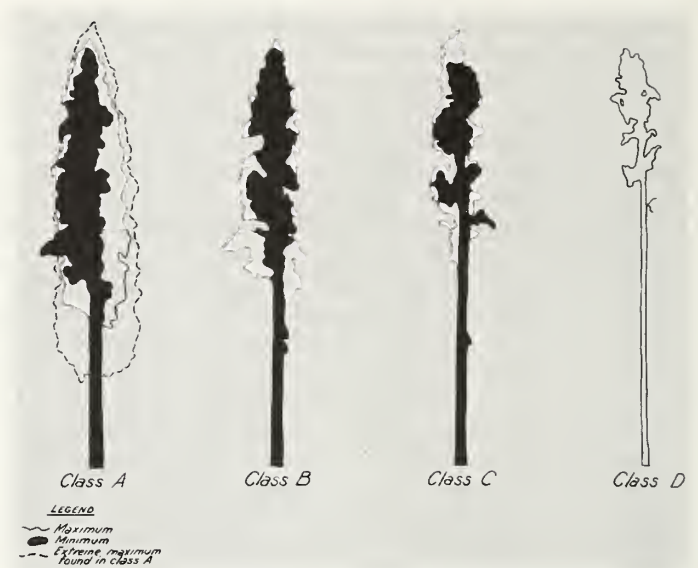

Figure 10.—Lodgepole pine tree vigor classes.

length, and vigor of the crowns of individual trees. Trees marked for removal should come from the lower vigor classes.

Vigor class A
1. Crown area: 30% or more of the "extreme outline" of vigor class A.
2. Crown length: 50% or more the bole length.
3. Crown vigor: Dense, full, good color, pointed.

Vigor class B
1. Crown area: Usually more than 30% but less than 50% of the "extreme outline" of vigor class A.
2. Crown length: Usually more than 50% but usually less than 60% of the bole length.
3. Crown vigor: Moderately dense, good color, pointed or slightly rounded.

Vigor class C
1. Crown area: 15% to 30% of the "extreme outline" of vigor class A.
2. Crown length: 40% to 50% of the bole length except for trees with above average vigor, when 20% of the bole length is sufficient.
3. Crown vigor: Sparse, bunchy, poor color, never pointed.

Vigor class D
1. All live trees of poorer vigor than class C. Includes trees in classes A, B, and C outlines but with dead or dying tops.

At the close of World War II, harvesting shifted back to clearcutting (LeBarron 1952, Lexen 1949). Traditionally, stands were clearcut either in blocks or strips (Alexander 1966b, LeBarron 1952, Lexen 1949, Tackle 1965). The pattern and size of opening depended upon the predominant cone habit (serotinous or nonserotinous) and the occurrence of dwarf mistletoe (Tackle 1965). The common practice has been to cut all merchantable trees, followed by removal of the unmerchantable residual to reduce dwarf mistletoe infection. Slash and logging debris usually were either (1) broadcast burned, dozer piled, or windrowed and burned, or (2) roller chopped

Figure 9.—Heavy blowdown in lodgepole pine after partial cutting that removed 60% of the basal area in the first entry, Fraser Experimental Forest, Colorado.

to reduce fire hazard and prepare seedbeds. Clearcuts usually restocked naturally if logging slash bearing serotinous cones was carefully handled or openings were small where cones were nonserotinous (Alexander 1966a, Tackle 1964, 1965). However, both artificial and natural regeneration efforts failed where seed was burned in slash fires, openings were too large to be seeded in from the side, or opening up the site created difficult microenvironments (USDA Forest Service 1971).

REGENERATION SILVICULTURAL SYSTEMS

Old-growth lodgepole pine forests are generally harvested by clearcutting, shelterwood, and group selection cutting, and by modifications of these methods. Seed-tree cutting usually is not applicable as a regeneration method because of susceptibility of residual trees to windthrow. Although the silvical characteristics of lodgepole pine do not readily lend themselves to individual tree selection cutting, it can be used in areas where vertical diversity and different tree sizes intermingled on the same site are desired (Alexander 1974, Alexander et al. 1983). The objective of each regeneration system is to harvest the timber crop and obtain adequate reproduction. The choice of cutting method in lodgepole pine stands depends upon management goals; but stand conditions, windfall, disease and insect susceptibility, and the risk of potential fire damage that vary from place to place limit the options available for handling individual stands. Furthermore, the economics of harvesting, manufacturing, and marketing wood products from many small diameter trees in the central Rocky Mountains has further limited cutting practices. Cutting to bring old-growth lodgepole pine under management may be a compromise between what is desirable and what is possible. Management on many areas may involve a combination of clearcutting small areas, several partial cutting treatments, and no cutting (Alexander 1974, 1975).

EVEN-AGED CUTTING METHODS

Clearcutting is the preferred even-aged method for old-growth lodgepole pine and has been used almost exclusively since the end of World War II because of several factors. (1) Lodgepole pine, a pioneer species, is shade-intolerant and reproduces best in most instances when overstory competition is removed or drastically reduced. (2) Dwarf mistletoe—present in many stands in varying degrees—is best controlled by separating the old stand from the new. (3) Windfall and mountain pine beetles, while variable, are always a threat. (4) The potential for future growth is limited because of the generally low vigor of mature and overmature stands and the suppressed condition of many smaller trees. Furthermore, many natural stands appear to be even-aged, having developed after catastrophic fires or other disturbances.

Shelterwood cutting in lodgepole pine is applicable in stands where (1) management objectives or environmen-

tal constraints preclude clearcutting and dwarf mistletoe infection is low, (2) regeneration requirements include overstory shade and an on-site seed source, or (3) a manageable stand of advanced regeneration exists.

Management with Advanced Regeneration

Simulated Shelterwood Cutting

This cutting method removes the overstory from a manageable stand of advanced reproduction in one or more operations. It simulates the final harvest of a standard shelterwood.

There seldom is a manageable stand of advanced regeneration under pure lodgepole pine, or if one is present, it has been suppressed for so long that it has no future management potential. In mixed stands, where the associated species are spruce and fir, there frequently is a stand of advanced reproduction. These trees will respond to release after cutting; but wide variations in age, composition, quality, and quantity of advanced reproduction require careful evaluation of the potential for future management. One course of action is followed if the advanced reproduction is to be managed, another if a manageable stand is not present, cannot be saved, is not expected to grow well, or the manager chooses to destroy it and start over.

Prelogging evaluation.—The initial examination must answer the following questions: (1) How much of the area is stocked with acceptable seedlings and saplings, and will that stocking insure a satisfactory replacement stand? (2) Can it be logged economically by methods that will save advanced reproduction? Is the timber volume too heavy to save advanced reproduction if it is removed in one cut? (3) How much of the area will require subsequent natural or artificial regeneration, either because advanced reproduction is not present or will be damaged or destroyed in logging?

Because any kind of cutting is likely to destroy at least 50% of the advanced spruce and fir growth in mixed lodgepole pine stands, a manageable stand of advanced reproduction before cutting should contain at least 600 acceptable seedlings and saplings per acre, at least 50% of which should be spruce. There are few data available on the growth response of advanced reproduction after release in the central and southern Rocky Mountains, but in the Intermountain Region, McCaughey and Schmidt (1982) found that both advanced spruce and fir made good height growth after clearcutting and partial cutting in spruce-fir stands. The following criteria, therefore, are based largely on experience and observation. To be acceptable, reproduction must be of good form, able to make vigorous growth when released, and be free of defect or mechanical injury that cannot be outgrown. Trees larger than 4 inches d.b.h. may be acceptable; but they should not be included in the prelogging regeneration survey because they are more likely to be damaged or destroyed in logging or windthrown after logging. Stands or portions of stands not meeting

these criteria have to be restocked with subsequent natural or artificial regeneration.

Cutting and slash disposal treatment.—Mature and overmature trees should be cut to release advanced spruce and fir reproduction and harvest merchantable volume. Seed sources need not be reserved from cutting unless required for fill-in stocking. The size, shape, and arrangement of units cut is not critical for regeneration; but to be compatible with other key uses, they should be irregular in shape and blend into the landscape. Not more than one-third of any drainage or working circle should be cut over at any one time.

Protection of advanced reproduction begins with a well-designed logging plan. Logging equipment and activity must be suited to the terrain and rigidly controlled to minimize damage of advanced reproduction and disturbance to soil. Skid roads should be located at least 200 feet apart and marked on the ground before cutting. Skidding equipment should be moved only on skid roads. Where possible, trees should be felled into openings at a herringbone angle to the skid road to reduce disturbance when logs are moved onto the skid road. It may be necessary to deviate from a herringbone felling angle in order to drop the trees into openings. In this case, the logs will have to bucked into short lengths to reduce skidding damage. Furthermore, the felling and skidding operations must be closely coordinated, because it may be necessary to fell and skid one tree before another is felled. Dead sound material and snags that are felled should be skidded out of the area to minimize the amount of slash and unmerchantable material. In stands with heavy volumes per acre, it may be necessary to remove the overstory in more than one cut.

Slash treatment then should be confined to areas of heavy concentrations as required for protection from fire and insects or preservation of esthetic values. Slash also must be treated carefully to avoid damage to advanced reproduction. If trees are felled into openings as much as possible, a minimum of turning and travel with brush dozers will be needed to concentrate the slash for burning. Slash piles should confine burning to the smallest total area possible.

Postlogging reevaluation.—Even with careful logging and slash treatment, some advanced reproduction will be damaged or destroyed. The area must be surveyed to: (1) Determine the extend of damage to the reproduction. In mixed lodgepole pine stands, at least 300 acceptable seedlings and saplings per acre, of which at least 50% should be spruce, must have survived to consider the area adequately stocked. This is in addition to any trees larger than 4 inches d.b.h. that survived. Areas that do not meet these standards will need fill-in or supplemental stocking. (2) Plan stand improvement—cleaning, weeding, and thinning—to release crop trees. Cutover areas should not be considered in an adequate growing condition until the crop trees are free to grow and the necessary fill-in planting or natural regeneration is complete. It is especially important to remove larger regeneration that has been broken off or has basal wounds. These trees can occupy considerable area and eventually become culls because of damage and decay.

Management for Natural Regeneration After Cutting

Clearcutting

This method harvests the timber crop in one step to establish a new stand. Because much of the lodgepole pine type in the central Rocky Mountains has little potential for future management because of advanced age, relatively slow growth, and susceptibility to wind, diseases, and insects, forest managers concerned with timber production have usually decided to convert old-growth to managed stands by clearcutting in strips, patches, and blocks (fig. 11). Therefore, harvesting and regeneration practices developed in the central Rocky Mountains have been directed toward this objective.

Cutting unit layout, logging plans, slash disposal, and seedbed treatment should be designed to (1) facilitate seed dispersal, (2) promote seedling survival and establishment, and (3) create favorable growing conditions. If natural regeneration fails, plans must be made to use artificial regeneration. Clearcutting can be readily adapted to multiple-use land management by judicious selection of size, shape, and arrangement of openings in combination with other high-forest cutting practices (Alexander 1974, Alexander et al. 1983).

Size of opening.—Successful natural regeneration of lodgepole pine depends upon an adequate supply of seed falling on a receptive seedbed. In the central Rocky Mountains, there are no data on seed:seedling ratios; but Lotan and Perry (1977) estimated seedling survival in relation to number of sound seeds on different seedbeds in the Targee National Forest, Idaho, for an *Abies lasiocarpa/Vaccinium scoparium* habitat type. They estimated that the number of sound seeds required to produce 1,200 5-year-old seedlings per acre—a desirable stocking goal—in relation to seedbed treatments on these cool moist sites was as follows.

Seedbed treatment	Number of sound seeds for 1,200 seedlings
Natural undisturbed	615,000
Piled and burned	560,000
Disked with lightweight harrow	95,000
Stand scalped to simulate dozer scalping	185,000
Hand scalped and cultivated	40,000
Hand scalped, cultivated, and sprayed with dalapon	75,000
Simulated brushblade scarification	65,000
Furrowed-vertical sides	35,000
V-shaped trenched	60,000

The size of opening that is likely to receive sufficient seed to restock receptive seedbeds is influenced by whether the seed is dispersed by open or closed cones. The manager cannot assume that the cone habitat is either serotinous or nonserotinous. Each area must be

examined and each stand classified as (1) closed cone (90% or more of the cones on individual trees are closed), (2) open cone (10% or less of the cones on individual trees are closed), or (3) intermediate (less than 90% but more than 10% of the cones on individual trees are closed). If the stand is classified as closed cone, the manager must then determine if there is enough sound seed stored in closed cones to provide an adequate seed source for natural regeneration, using the procedures developed by Lotan and Jensen (1970).

The size and shape of openings cut in stands with serotinous cone habitat that will restock is highly flexible if there is enough seed. Natural regeneration is a one-shot opportunity, however, because the seed supply is in the slash-borne cones, and nearly all cones will open in the first 2 years after cutting. There is no advantage to cutting openings larger than 30 to 40 acres, even for dwarf mistletoe control, and openings 10 to 20 acres would be more compatible with other uses (fig. 12). On south slopes and other difficult regeneration areas, it may be desirable to cut openings smaller than 10 acres to provide a supplemental seed source in trees standing around the perimeter. If there is not an adequate supply of seed in closed cones, the recommendations following apply.

In stands with nonserotinous or intermediate cone habitat, the cutting unit must be designed so that seed from the surrounding timber margin reaches all parts of the opening, unless artificial regeneration is planned. Effective seed dispersal distance from standing trees has not been studied in the central Rocky Mountains; but studies elsewhere, summarized by Lotan and Perry (1983), indicate that, with favorable seedbed and environmental conditions, the effective seeding distance in lodgepole pine is about 150 to 200 feet. The maximum width of opening likely to restock to natural reproduction, therefore, is 300 to 400 feet, or about five to six times tree height. Furthermore, it is not likely that only one seed crop will provide sufficient seedfall for adequate stocking. On south slopes, openings should be smaller—150 to 200 feet wide or about two to three times tree height. If larger openings are cut, plan on planting the area beyond effective seeding distance.
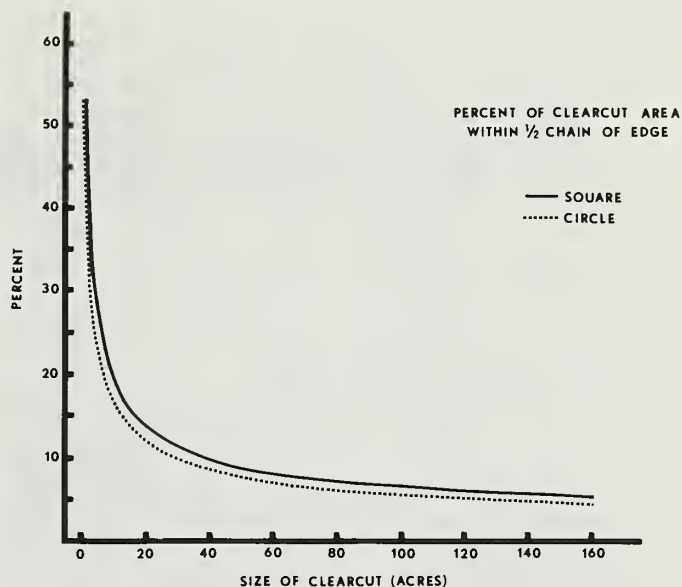

Figure 12.—Amount on area clearcut in relation to perimeter.

Windfall.—The following guidelines for minimizing windfall around the perimeter of clearcut openings were developed in Colorado (Alexander 1964, 1967, 1974).

1. Protection from wind for the vulnerable leeward boundaries is most important.

2. Do not locate cutting boundaries where they will be exposed to accelerated winds funneling through saddles in ridges to the south and west of the cutover area, especially if the ridges are at high elevations (fig. 5).

3. Avoid locating cutting boundaries on ridges or directly below saddles in ridges (fig. 13), especially ridgetops of secondary drainages to the lee and at right angles to the main drainage when the latter is a narrowing valley with steep slopes. One cutting unit should straddle each ridgetop and extend downslope in both directions for a distance of at least 200 feet. That unit may be cut or uncut. Such an arrangement will avoid leaving a cutting boundary on the top of a ridge (fig. 14).

4. Where topography, soils, and stand conditions permit, lay out each unit so that the maximum amount of cutting boundary is parallel to the contour or along a road (fig. 15).

5. Do not lay out cutting units with dangerous wind-catching indentations (fig. 16) or long, straight lines and square corners in the leeward boundary or in boundaries that are parallel to storm winds. V- or U-shaped identations in the boundary can funnel wind into the reserve stand. Long, straight cutting boundary lines and square corners also deflect the wind and cause increased velocities where the deflected currents converge like a windstream flowing over a crest. Irregular cutting boundaries without sharp identations or square corners lessen the opportunity for deflection and funneling of air currents.

Figure 11.—Clearcut patch in a lodgepole pine stand on the Fraser Experimental Forest.

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6. Do not locate boundaries on poorly drained or shallow soils. Trees grown under these conditions are shallow rooted and susceptible to windthrow.

7. Locate cutting boundaries in stands of sound trees. Trees with decayed roots and boles or root systems that were cut or torn during road building or log skidding operations are poor windfall risks.

8. Locate cutting boundaries in immature stands when possible. Stands of young trees usually are less easily uprooted by strong winds.

9. Locate cutting boundaries in poorly stocked stands. Open-grown trees are more windfirm than trees grown in dense stands.

10. Avoid locating cutting boundaries in areas where there is evidence of old prelogging blowdowns.

11. Reduce blowdown in areas with exceptionally hazardous windfall potential by locating the vulnerable leeward boundaries where hazards are below average, or by eliminating those boundaries by progressive cutting into the wind.

Slash treatment and site preparation.—In stands with serotinous cones, careful handling of slash is required (1) to avoid destruction of seed-bearing cones; (2) heavy concentrations of slash obstruct seedling establishment and are a fire hazard; and (3) slash creates an adverse visual impact (Alexander 1974).

In stands with serotinous cone habit, dozer piling or windrowing dry slash over the entire area usually results in overly dense stands of reproduction, because abundant seed is shaken out of cones onto exposed mineral soil seedbeds (Alexander 1966a, Tackle 1964). Dozer piling and windrowing slash, then burning the concentrated slash, frequently results in poor stocking, especially when the slash fires burned over much of the area and destroyed most of the seed or created enough heat in the soil to inhibit any kind of plant growth for a long time. Broadcast burning usually results in little or no restocking, because most of the seed is destroyed. Disposal of slash by lopping and scattering, and by rolling and chopping have resulted in adequate restocking, if sufficient mineral soil (about 40% of the area) has been exposed and the seed-bearing cones are placed near the ground. Fire hazards and visual impact are usually not reduced sufficiently, however.

Concentrations of slash must be treated. If these concentrations are piled or windrowed for burning, the piles and windrows must be kept small (1/20 acre or less) and well distributed so that the burned area does not occupy more than 25% of the total area. The lighter areas of slash—less than 40% of the area covered with slash less than 1 foot deep—either can be lopped and scattered or rolled and chopped. This combination of treatments will reduce fire hazards and visual impact, provide exposed mineral soil, scatter the cone-bearing slash over the area, and place the cones near or on the ground (Alexander 1974).

In stands with nonserotinous or intermediate cone habit, slash can be handled in the same way as in stands with serotinous cones, or it can be broadcast burned. If slash is piled or windrowed for burning, the piles should be kept small and well distributed, because burning in
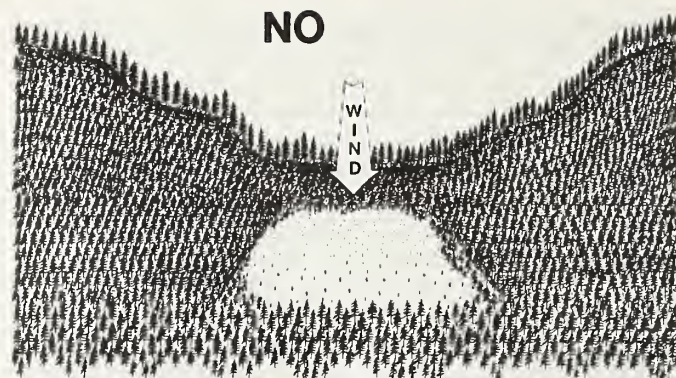
Figure 13.—Clearcut opening directly below a saddle where wind vortexing can occur and increase blowdown risk.

Figure 14.—Clearcut unit boundary on a ridgetop where risk of blowdown is increased.

Figure 15.—Clearcut unit boundaries laid out across the slope that exposes the short dimensions of the unit to the wind helps reduce blowdown.
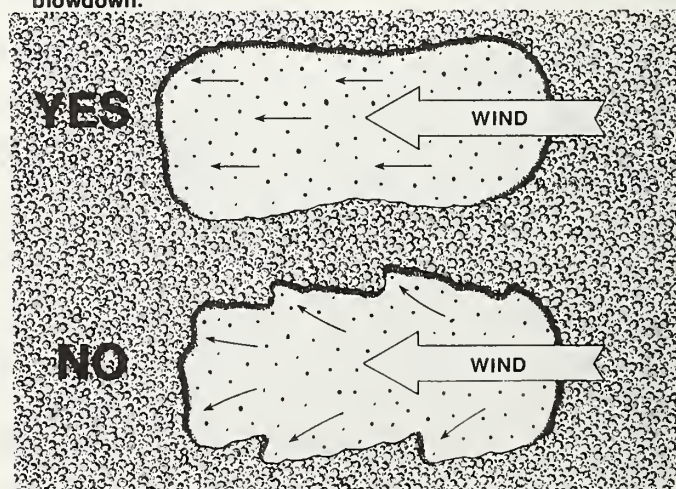

Figure 16.—Irregular cutting boundaries with sharp indentations or square corners help reduce blowdown.

large concentrations often heats the soil enough to inhibit subsequent plant growth. To be effective, broadcast burning should cover about 75% of the area. It should consume most, but not necessarily all, of the logging slash, other debris, and duff or organic material on the ground, and it should burn hot enough to destroy most of the competing vegetation. It should not burn so hot, however, that a deep layer of loose ash accumulates. Areas with light slash can be lopped and scattered or rolled and chopped. It may be necessary to do some additional mechanical scarification on lopped and scattered areas. Tractors with brush blades should be used, and about 40% of the area should be left with exposed mineral soil (Alexander 1974).

Shelterwood Cutting

This regeneration cutting method harvests a timber stand in a series of cuts. In a standard shelterwood, the new stand regenerates under the shade of a partial overstory canopy. The final harvest removes the shelterwood and permits a new stand to develop in the opening. In a group shelterwood (a modification of the shelterwood method), the new stand regenerates in small openings that leave standing trees around the margins as a seed source. Openings are too small (2 acres or less) to be classified as a clearcut. This kind of cutting has been incorrectly called a modified group selection, but differs from a selection cut in the way the growing stock is regulated.

These cutting methods may be the only even-aged options open to the manager where (1) multiple use considerations preclude clearcutting, (2) combinations of small cleared openings and high forests are required to meet the needs of various uses, or (3) areas are difficult to regenerate after clearcutting. However, shelterwood cutting requires careful marking of individual trees or groups of trees to be removed, and close supervision of logging. The following recommendations for shelterwood cutting practices are keyed to broad stand descriptions based largely on experience, windfall risk situations, and disease and insect problems (Alexander 1974, 1975). Stands are pure pine unless otherwise indicated.

Single-storied stands.—These may appear to be even-aged (fig. 17), but often contain more than one age class, occasionally may even be broad-aged. Codominants form the general level of the canopy; but the difference in height between dominants, codominants, and intermediates is not as great as in spruce-fir stands. If stands are even-aged in appearance, there is a small range in diameter class and crown length; live crown length of dominants and codominants is generally short to medium (30% to 60% of the total height and boles are generally clear for 10% to 40% of total tree height); and there are few coarse-limbed trees in the stand.

With two or more age classes, the younger trees usually have finer branches, smaller diameter, longer live crown, and less clear bole than older trees. Stocking is generally uniform. A manageable stand of advanced reproduction is usually absent. In mixed stands, the overstory is

Figure 17.—A single-storied lodgepole pine stand.

either pure pine, or pine and Engelmann spruce, subalpine fir, or Douglas-fir, with advanced reproduction of species other than pine that may or may not be a manageable stand.

Single-storied stands usually are the least windfirm, because trees have developed together over long periods of time and mutually protect each other from the wind.

If windfall risk is low and stands are uniformly spaced, the first cut can remove about 30% of the basal area on an individual tree basis (fig. 18). This initial entry is a preparatory cut that resembles the first step of a three-cut shelterwood, because it probably does not open up the stand enough for significant pine reproduction to become established. Overstory trees are all about equally susceptible to blowdown; therefore, the general level of the canopy should be maintained by removing some trees in each overstory crown class. The cut should come from C and D vigor class trees; but openings larger than one tree height in diameter should be avoided by distributing the cut over the entire area. Do not remove dominant trees that are protecting other trees to their leeward if these latter trees are to be reserved for the next cut. In mixed stands, if the overstory is mostly pine, handle it as a pure stand; if the overstory is of mixed composition, cut as much of the basal area recommended in pine as is possible to release the climax species.

Single-Storied Stand
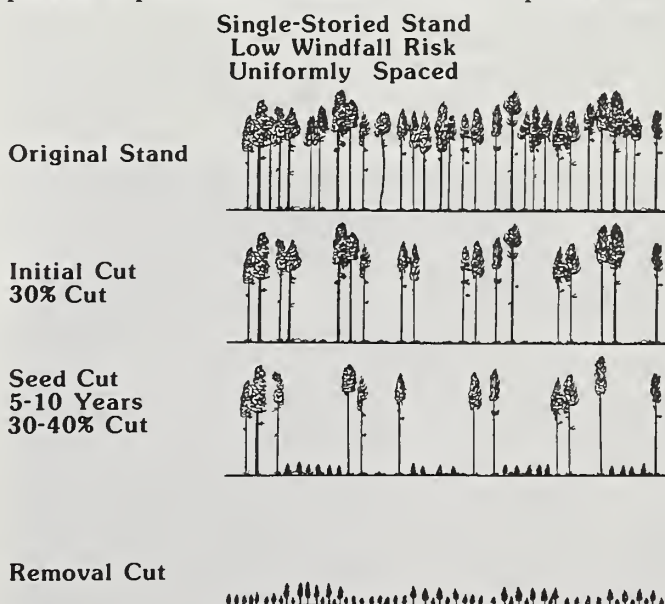Low Windfall Risk
Uniformly Spaced

Figure 18.—Sequence of entries with a three-cut shelterwood in a uniformly-spaced, single-storied lodgepole pine in a low wind risk situation.

The second entry into the stand should not be made until 5 to 10 years after the first cut in order to determine if the residual stand is windfirm. The second cut should remove 30% to 40% of the original basal area on an individual tree basis. It simulates the second or seed cut of a three-step shelterwood. The largest and most vigorous dominants and codominants should be reserved as a seed source in stands with the nonserotinous or intermediate cone habit; but avoid cutting openings in the canopy larger than one tree height in diameter by distributing the cut over the entire area even if it means leaving trees in the C and D vigor classes with poor seed production potential. In mixed stands, cut as much of the recommended basal area in pine as is possible without creating openings larger than one tree height.

The last entry into these uniformly-spaced stands is the final harvest, which should remove all of the remaining original overstory. It should not be made until a manageable stand of reproduction has become established; but the cut should not be delayed beyond this point if timber production is the primary concern, because the overwood (1) hampers the later growth of seedlings, and (2) if infected with dwarf mistletoe, it will reinfect the new stand (fig. 19).

The manager also has the option of removing less than 30% of the basal area at any entry and making more entries; but they cannot be made at more frequent intervals. The cut will be spread out and continuous high forest cover maintained for a longer period of time. This option is not recommended where mountain pine beetles and dwarf mistletoe impose limitations on how stands can be handled.

The usual uniform arrangement of individual trees in single-storied stands is not well adapted to removing trees by groups. Occasionally, however, natural openings occur when stands begin to break up. Also, small openings may be desirable to meet management objectives.

If windfall risk is low but trees grow in clumps or spacing is irregular, an alternative to removing trees on an individual basis would be to remove about 30% of the basal area using a group shelterwood (fig. 20). Openings

Single-Storied Stand
Low Windfall Risk
Clumps

Original Stand

Initial Cut
30% Cut

Second Cut
30-40% Cut

Removal Cut

Figure 20.—Sequence of entries with a group shelterwood in an irregularly-spaced, single-storied lodgepole pine in a low wind risk situation.

should be kept small, not more than one to two times tree height in diameter; not more than one-third of the area should be cut over at any one time. All trees in a clump either should be cut or left, because they mutually support each other, and removing only part of a clump is likely to result in windthrow of the remaining trees. This kind of cutting should be used only in stands where insect and disease problems are minimal.

The second entry into the stand should not be made until the first openings have been regenerated. This cut should remove about 30% to 40% of the original basal area without cutting over more than an additional one-third of the area. Openings should be no closer than about one to two tree heights to the original openings.

The final entry into these clumpy stands should remove the remaining groups of merchantable trees. The timing of this cut depends upon the cone habit and how the manager decides to regenerate the openings. If it is by natural regeneration and the stand is classified as nonserotinous or intermediate cone habit, the final harvest must be delayed until the trees in the original openings are large enough to provide a seed source.

In these stands, the manager again may choose to remove less than 30% of the basal area and cut over less than one-third of the area at any one time. This will require more entries; but new cuts should not be made until the openings cut the previous entry have regenerated. Furthermore, in stands with nonserotinous or intermediate cone habit, the last groups cannot be cut until there is either an outside seed source or the manager elects to plant these openings.

If windfall risk is moderate and trees are uniformly spaced, the first cut should be limited to a light preparatory cutting that removes about 20% of the basal area on an individual-tree basis (fig. 21). The objective is to open up the stand, but at the same time minimize the windfall risk to the remaining trees. Provision should

Figure 19.—New reproduction established after the seed cut of a three-cut shelterwood in lodgepole pine.

be made, however, to salvage blowdowns. This type of cutting resembles a sanitation cut, in that the lowest vigor and poorest risk trees should be removed; but it is important to maintain the general level of the overstory canopy intact. Mixed stands should be handled the same as in low windfall risk situations, except that less basal area should be removed.

The second entry can be made in about 5 to 10 years after the first cut. This entry should remove about 20% of the original basal area on an individual-tree basis. Windfalls that were salvaged after the first cut should be included in the computation of the basal area to be removed. The objective of this preparatory cut is to continue to minimize the risk of blowdown while preparing the stand for the seed cut. Most of the trees marked for removal should come from the smaller crown and poorer vigor classes; but maintain the general level of the canopy intact. In mixed stands, cut as much of the recommended basal area to be removed in pine as is possible.

It will require about another 5 to 10 years to determine if the stand is windfirm enough to make another entry. This will be the seed cut, and should remove about 20% of the original basal area including any windfalls since the last cutting. The largest and most vigorous dominants and codominants in mixed stands and pure stands with nonserotinous or intermediate cone habit should be reserved as a seed source; but it is more important to distribute the cut over the entire area.

Single-Storied Stand
Moderate Windfall Risk
Uniformly Spaced
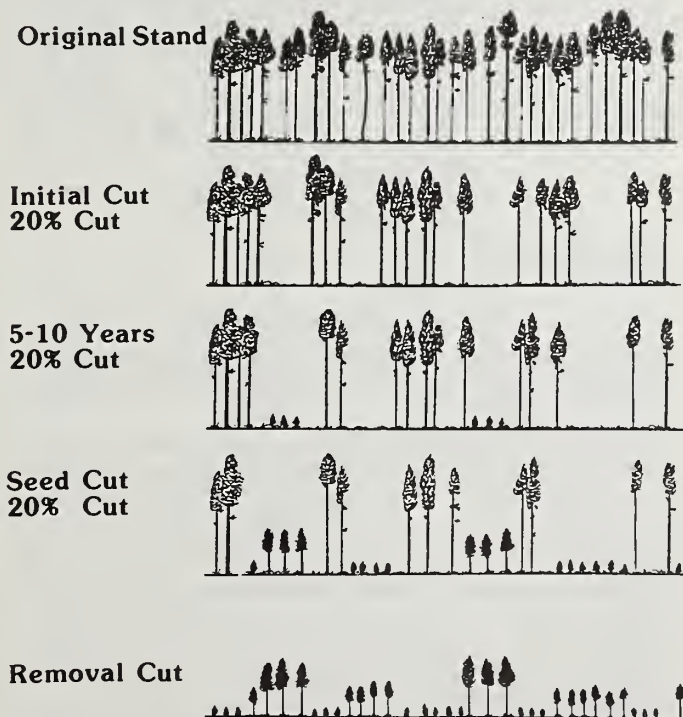

Figure 21.—Sequence of entries for a shelterwood in a uniformly-spaced, single-storied lodgepole pine stand in a moderate wind risk situation.

Single-Storied Stand
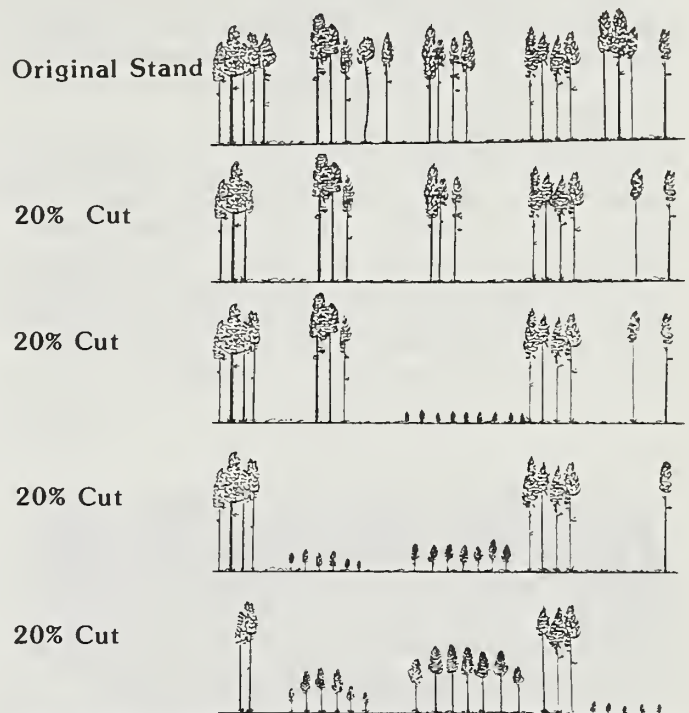### Moderate Windfall Risk
Clumps

Figure 22.—Sequence of entries with a group shelterwood in an irregularly-spaced, single-storied lodgepole pine stand in a moderate wind risk situation.

The last entry is the final harvest, which should remove the remaining original overstory. It cannot be made until a manageable stand of reproduction has been established. About 40% of the original basal area will be removed in this cut, and if it is too heavy (10,000 fbm or more per acre) to be removed in one harvest without undue damage to the reproduction, the manager must plan on a final harvest in two stages ("stage logging"). The second stage can begin as soon as skidding is finished in the first stage.

The manager also has the option of removing less than 20% of the basal area at any entry and making more entries; but they cannot be made at more frequent intervals.

If windfall risk is moderate and trees are clumpy or irregularly spaced, the first cut should be light, removing about 20% of the basal area in a group shelterwood (fig. 22). Openings should be no larger than one tree height in diameter, and not more than one-fifth of the area should be cut over at any one time. All trees in a clump should be cut or left. In stands with small natural openings—about one tree height in diameter—the openings can be enlarged one tree height by removing clumps of trees to the windward.

Four additional entries into the stand can be made at periodic intervals; but no new entry should be made until the openings cut the previous entry have regenerated. In stands with nonserotinous cones, the last groups to be removed should be retained until the original group openings are large enough to provide a seed source, or plan on planting the openings created by the last cut.

About 20% of the basal area should be removed over about one-fifth of the area at each entry. Group openings should be no larger than one tree height in diameter.

If windfall risk is very high, the choice is limited to removing all the trees or leaving the area uncut. Cleared openings should not be larger than regeneration requirements dictate, and they should be interspersed with uncut areas of at least equal size.

Two-storied stands.—These stands may appear to be two-aged (fig. 23), but can contain more than two age classes. Top story—dominants, codominants, and intermediates—resembles a single-storied stand. The second story is composed of younger trees of smaller diameter—small logs, poles, or saplings—than the top story; but it is always below and clearly distinguishable from the overstory. Trees in the second story are overtopped and may or may not be suppressed.

TWO-STORY

Figure 23.—A two-storied lodgepole pine stand.

If more than two-aged, the overstory usually contains at least two age classes. The younger trees are finer limbed and may be smaller in diameter than the older trees. The second story may also contain more than one age class. Stocking of the overstory may be irregular; but overall stocking is usually uniform. A manageable stand of advanced reproduction is usually absent.

In mixed stands, the overstory is usually pure pine; but occasionally it may be pine with spruce or Douglas-fir. The second story is usually spruce and fir at the higher elevations, and Douglas-fir at the lower elevations. Stocking in mixed stands may vary from uniform to irregular. Mixed stands may have a manageable stand of advanced reproduction of species other than pine.

Recommended cutting treatments are the same as for three-storied stands.

Three-storied stands.—These stands may appear to be three-aged (fig. 24); but they can contain more than three age classes, although stands are seldom broad-aged. The top story resembles a single-storied stand except that there are fewer trees. The second and third stories consist of younger, smaller diameter trees. The second story

THREE-STORY

Figure 24.—A three-storied lodgepole pine stand.

may be small saw logs or large poles, while the third story is likely to be composed of small poles or saplings. Second and third stories are overtopped, and some trees may be suppressed. Overall stocking is likely to be uniform, but stocking of any story may be irregular. A manageable stand of advanced reproduction is usually absent.

In mixed stands, the top story may be either pure pine or a mixture of pine and other species. The second story is usually spruce and subalpine fir at the higher elevations, and Douglas-fir at the lower elevations. The second story occasionally may contain some pine; but it is rarely pure pine. The third story almost always is composed of species other than pine. Stocking in mixed stands can vary from uniform to irregular. Mixed stands often have a manageable stand of advanced reproduction of species other than pine.

Trees in the top story of two- and three-storied stands usually are more windfirm than those in a single-storied stand. Trees in the second and third stories usually are less windfirm than trees in the top story.

If windfall risk is low and trees uniformly spaced, the first cut can remove up to 50% of the basal area in two-storied stands (provided that not more than 50% of the basal area removed comes from the top story), and up to 40% of the basal area from three-storied stands (fig. 25). This cutting is as heavy as the first or seed cut of a two-cut shelterwood; but marking follows the rules for

**2 & 3-Storied Stands
Low Windfall Risk
Uniformly Spaced**

Figure 25.—Sequence of entries with a two-cut shelterwood in a uniformly-spaced, two- or three-storied lodgepole pine stand in a low wind risk situation.

individual-tree selection. Heavier cutting may be possible in three-storied stands; but the appearance of a continuous overstory is not likely to be retained. Trees removed should be in vigor classes C and D as much as possible; but because the top story is likely to be more windfirm, selected dominants and codominants should be left even when they are in vigor classes C and D, if they do not have dead or dying tops. Avoid cutting holes in the canopy larger than one tree height in diameter by distributing the cut over the entire area. Do not remove dominant trees that are protecting other trees to their leeward if these latter trees are to be reserved for the next cut. In a mixed stand, if the top story or, rarely, the first

and second stories are pure pine, handle it as a pure stand. If the top story is of mixed composition, cut as much of the basal area to be removed in pine as is possible to release the climax species; but do not cut all of the pine if it is needed to maintain the overstory.

The second entry should be the final harvest to remove the remaining original stand and release the reproduction. It cannot be made until the new stand of reproduction is established. If the residual volume is greater than about 10,000 fbm per acre, the final harvest should be made in two stages to avoid undue damage to newly established reproduction. The second stage can begin as soon as skidding is finished in the first stage.

If there is a manageable stand of advanced reproduction under mixed stands, the first cut can be a simulated shelterwood if the volume is not too heavy. Otherwise, the first cut can remove 40% to 50% of the basal area on an individual-tree basis as long as the more windfirm dominants and codominants are left. The timing of the second cut is not critical from a regeneration standpoint, provided that a manageable stand of reproduction still exists after the first cut and can be saved.

The manager has other options to choose from, including cutting less than the recommended basal area, making more entries, and spreading the cut out over a longer period of time by delaying the final harvest until the new stand is tall enough to create the appearance of a high forest. This is not recommended where mountain pine beetles and dwarf mistletoe limit the way stands can be handled.

If windfall risk is low and trees grow in clumps or spacing is irregular, in pure or mixed stands with irregular or clumpy stocking that may have resulted from the breakup of single-storied stands, old beetle attacks, or windfall losses, an alternative first cut can remove about 40% of the basal area in a group shelterwood (fig. 26). The group openings can be larger (two or three times tree height) than in single-storied stands; but the area cut

Figure 27.—Sequence of entries with a three-cut shelterwood in a uniformly-spaced, two- or three-storied lodgepole pine stand in a moderate wind risk situation.

over should not exceed about one-third of the total. Openings should be irregular in shape without windcatching indentations in the borders. This kind of cutting is not applicable in pure stands where mountain pine beetle or dwarf mistletoe impose limitations; because the interval between initial cutting and final harvest is likely to be too long to prevent serious mistletoe infection of new reproduction and/or loss of beetle-susceptible trees.

Two additional entries can be made in the stand. They should each remove about 30% of the original basal area in group openings up to two to three times tree height; but not more than one-third of the area should be cut over at any one time. If there is not a manageable stand of advanced reproduction, the manager must wait until the first openings are regenerated before cutting the second series. Furthermore, in mixed stands, or pure stands with the nonserotinous or intermediate cone habit, cutting the final groups either must be delayed until there is a seed source or these openings must be planted. If there is a manageable stand of advanced reproduction, the timing between cuts is not critical for regeneration.

The manager has the option in mixed stands of removing less than the recommended basal area and cutting less than the recommended area at any one time. This will require more entries and spread the cut out over a longer period of time.

If windfall risk is moderate and trees are uniformly spaced, the first entry should be a preparatory cut that removes not more than 30% of the basal area on an individual-tree basis (fig. 27). Predominants, and codominants, and intermediates with long live crowns should be removed first. The remaining cut should then come from trees in vigor classes C and D. Maintain the general level of the canopy by not cutting holes larger than one tree height in diameter in the canopy. Provision should be made to salvage blowdowns. Mixed stands should be handled as in low wind risk situations, except that less basal area should be removed.
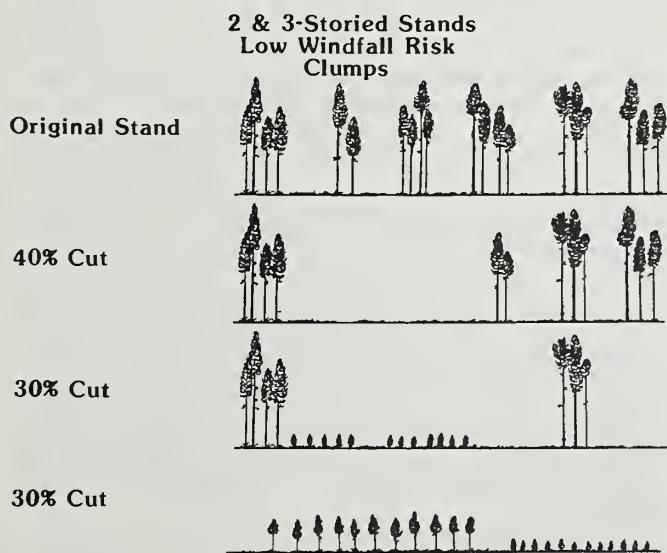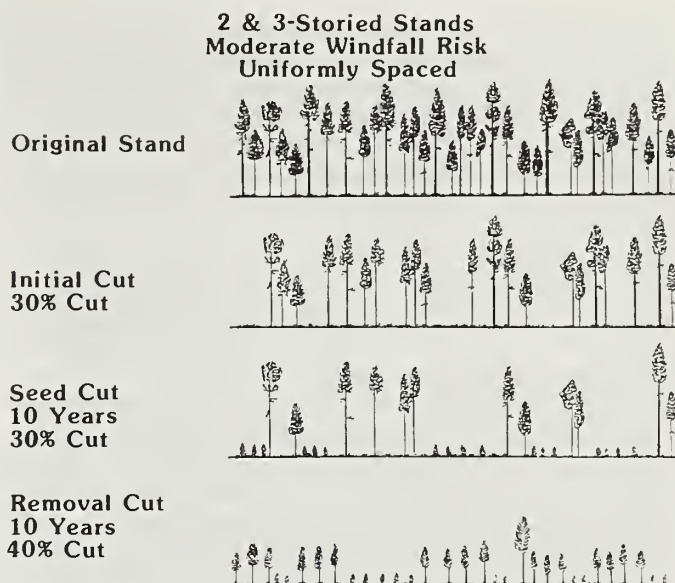

Figure 26.—Sequence of entries with a group shelterwood in an irregularly-spaced, two- or three-storied lodgepole pine stand in a low wind risk situation.

15

The second entry should not be made in less than 10 years. This cut should remove about 30% of the original basal area, including the salvage of any windfalls after the first cut. During this seed cut, the best dominants and codominants should be reserved as a seed source in stands with the nonserotinous or intermediate cone habit; but it is important that the cut be distributed over the entire area.

The next entry is the final harvest to remove the remaining merchantable volume and release the new reproduction after it has become established. However, if the residual stand volume is too heavy, the final harvest should be made in two steps.

In mixed stands that contain a manageable stand of reproduction, where the volume per acre is not too heavy, the first cut can be a simulated shelterwood. If the volume is too heavy for a one-step removal, the manager should follow the recommendations for pure stands, because the wind hazard is too great to permit a two-step removal in a stand that has not been previously opened up to develop windfirmness.

If windfall risk is moderate and trees are clumpy or irregularly spaced, the first cut should be a group shelterwood that removes about 25% of the basal area (fig. 28). Openings should be kept small—not more than one or two tree heights in diameter—and not more than one-fourth of the area should be cut over at any one time. All trees in a clump either should be cut or left. Small natural openings can be enlarged one or two tree heights by removing trees in clumps to windward of the opening.

2 & 3-Storied Stands
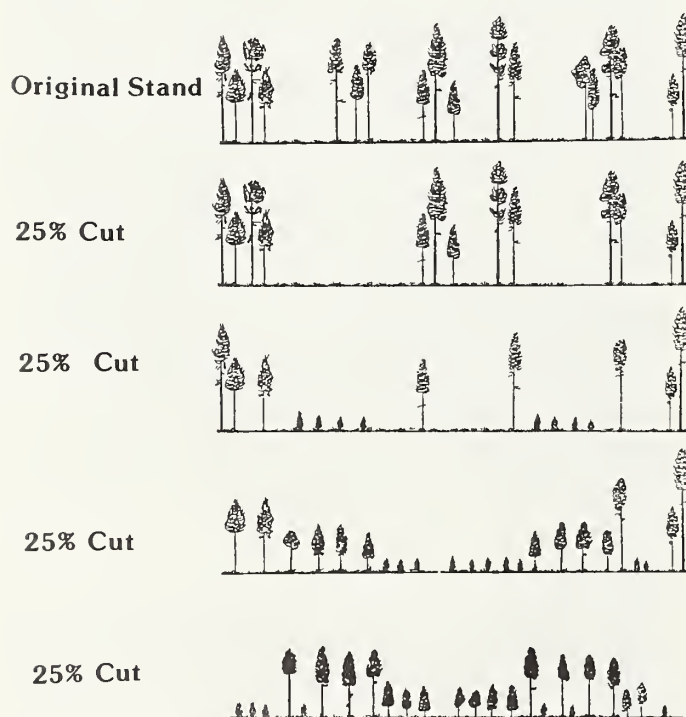### Moderate Windfall Risk
Clumps

Figure 28.—Sequence of entries with a group shelterwood in an irregularly-spaced, two- or three-storied lodgepole pine stand in a moderate wind risk situation.

Three additional entries should be made. About 25% of the original basal area should be removed on about one-fourth of the area in each entry. The interval between cuts will depend upon the time required to regenerate each series of openings. The manager must either delay the removal of the final groups until a seed source is available or plant the openings.

If windfall risks are very high, the choice usually is limited to removing all the trees or leaving the area uncut. Cleared openings should not be larger than regeneration requirements dictate, and should be interspersed with uncut areas. Not more than one-third of the total area in this windfall risk situation should be cut over at any one time.

Multi-storied stands.—These stands are usually broadaged (fig. 29) with a wide range in diameters. If stands developed from relatively few individuals following disturbance, the overstory trees are coarse limbed. Fill-in trees are better formed and finer limbed. Vigor of the overstory trees varies from poor to good. In stands that developed from deterioration of single- or two-storied stands, the overstory trees may be no limbier than the fill-in trees. Nearly all of the healthy, faster growing trees are below saw-log size. Stocking may be irregular. A manageable stand of advanced reproduction may be present.

In mixed stands, the overstory may be either (1) pure pine, or (2) a mixture of pine, spruce, and fir at the higher elevations, or pine and Douglas-fir at lower elevations. Overstory trees have the same characteristics as pure stands, except that the composition is likely to be other than pine. Stocking in mixed stands is more likely to be irregular. Mixed stands frequently have a manageable stand of advanced reproduction of species other than pine. These are usually the most windfirm stands, even where they have developed from the deterioration of single- and two-storied stands. By the time they have reached their present condition, the remaining overstory trees are likely to be windfirm.

If windfall risk is low, there is considerable flexibility in harvesting these stands. All size classes can be cut, with emphasis on either the largest or smallest trees in the stand. The first cut can range from an overwood removal to release the younger growing stock, to a thinning from below to improve the spacing of the more vigorous of the larger trees. Thereafter, cutting can be directed toward either even-aged or uneven-aged management (fig. 30). In mixed stands, the first cut should be a simulated shelterwood that removes the overstory pine to release the climax species. The understory trees should be thinned to improve spacing.

If windfall risk is moderate to high, the safest first cut is an overwood removal with a light thinning from below to obtain a wider spaced, more open stand that can develop windfirmness. Thereafter, cutting can be directed toward either uneven- or even-aged management (fig. 31).

Modification to partial cutting practices imposed by disease and insect problems.—For dwarf mistletoe, cut only in stands where the average mistletoe rating is 2 or less, and remove only the percentage of basal area

MULTI — STORY

Figure 29.—A multi-storied lodgepole pine stand.

Multi-Storied Stands
Low Windfall Risk

Original Stand

First Cut Options
1. Overwood Removal

2. Thin From Below

Figure 30.—Sequence of entries in a multistoried lodgepole pine stand in a low to moderate wind risk situation.

Multi-Storied Stands
Moderate-High Windfall Risk

Original Stand

Overwood
Removal and
Thin From Below

Figure 31.—Sequence of entries in a multistoried lodgepole pine stand in a high wind risk situation.

recommended for the stand description and windfall situation. In single-storied stands, where site index is 70 or above, trees in the intermediate and lower crown classes should be removed before dominants and codominants. If site index is below 70, trees in all crown classes are about equally susceptible to infection. In two- and three-storied stands, as much of the first cut as is possible should come from the second and third stories, because these trees are likely to be more heavily infected than the top story. In single-, two-, and three-storied stands, the final overstory removal can be delayed until the new reproduction is tall enough to provide a forest aspect. To minimize infection of new reproduction, however, time interval should not exceed 30 years after the regeneration cut when the average mistletoe rating is 1, or 20 years when the rating is 2. Provision should be made to sanitize the young stand at the time of final harvest (Hawksworth et al. 1977). In multi-storied stands,

the safest procedure is an overwood removal with a cleaning and thinning from below.

In old-growth stands with an average mistletoe rating greater than 2, any partial cutting, thinning, or cleaning is likely to intensify the infection. The safest procedure, therefore, is either to remove all of the trees and start a new stand or to leave the stand uncut. If the manager chooses to make a partial cut for any reason, the initial harvest should be heavy enough to be a regeneration cut. All residual trees must be removed within 10 years after the first cut, and provision made to sanitize the young stand at that time.

For comandra blister rust, cut as many trees with stem cankers and spike-tops as possible in the first cut without removing more than the recommended basal area or cutting large openings in the canopy. Because the rate of spread in mature trees is relatively slow and the disease is not transmitted from pine to pine, leaving a few infected trees is less of a risk than opening up the stand too much.

If mountain pine beetle is present in the stand at an endemic level, or in adjacent stands in sufficient numbers to make successful attacks, and less than the recommended percentage of basal area to be removed in the first cut is in susceptible trees, any attacked tree and all of the most susceptible trees should be removed in the first cut. This will include most of the trees 12 inches d.b.h. and larger, and all trees 10 to 12 inches d.b.h. in vigor classes A and B. Provision should be made to salvage attacked trees, and the second cut should be made within 10 years of the first cut.

If, in these stands, more than the recommended percentage of basal area to be removed in the first cut is in susceptible trees, the manager has three options:

(1) remove all the trees, burn the green culls and unmerchantable portions of trees, and regenerate a new stand; (2) remove the recommended basal area in attacked and susceptible trees and accept the risk of future losses; or (3) leave the stand uncut. If the stand is partially cut or left uncut, some trees from 5 to 12 inches d.b.h. will survive.

If the stand is sustaining an infestation that is building up, and the manager chooses to either partially cut or leave the stand uncut, there is a risk of an outbreak that could destroy most of the stand 5 inches d.b.h. and larger.

Cutting to save the residual.—In shelterwood cutting, protection of the residual stand from logging damage is a primary concern. The residual stand includes merchantable trees left after standard shelterwood and reproduction established after the seed cut in standard shelterwood, and reproduction established after each cut in group shelterwood. Before the final harvest is made with standard shelterwood, and before each entry with group shelterwood, the manager must determine if there is an acceptable stand of reproduction. Furthermore, the stand must be reevaluated after final harvest in standard shelterwood and after each entry with group shelterwood to determine the need for supplemental stocking. The same criteria used to minimize damage and evaluate

advanced reproduction with a simulated shelterwood applies here (fig. 32).

Slash disposal and seedbed preparation.—Some treatment of logging slash and unmerchantable material probably will be needed after each cut. Treatment should be confined to concentrations and that needed to reduce visual impact, however, because most equipment now available for slash disposal is not readily adaptable to working in shelterwood cuttings. Furthermore, burning slash will not only cause damage to the residual stand, but may destroy the seed supply in stands with serotinous cones. Skid out as much of the downed sound dead and green cull material as possible for disposal at the landings or at the mill. Treatment in stands should be limited to lopping and scattering, chipping along the roadway, and hand piling and burning to minimize damage. In group shelterwood cutting, if there is not a manageable stand of advanced reproduction, dozers equipped with brush blades can be used to concentrate slash for burning in the openings. Piles should be kept small to reduce the amount of heat generated. Stands with the serotinous cone habit should not be treated until the cones have had time to dry out and open up (Alexander 1974).

On areas to be regenerated, a partial overstory canopy or trees standing around the margins of small openings provide two of the basic elements necessary for regeneration success in stands with the nonserotinous or intermediate cone habit—a seed source within effective seeding distance, and an environment compatible with germination, initial survival, and seedling establishment. In stands with the serotinous cone habit, the seed supply is largely in the cones attached to the slash or scattered on the ground. The manager must make sure that the third element—a suitable seedbed—is provided after the regeneration cut where standard shelterwood cutting is used, and after each cut where group shelterwood is used. Unless at least 40% of the available ground surface is exposed mineral soil after logging and slash disposal, additional seedbed preparation is needed. Until special equipment is developed, seedbed preparation as well as slash disposal will pose problems. The equipment

currently available is too large to work well around standing trees. Small dozers or other machines equipped with brush blades will have to be used (Alexander 1974).

UNEVEN-AGED CUTTING METHODS

Normally, lodgepole pine is best maintained as a vigorous, productive forest under even-aged cutting methods. However, multi- and three-storied stands frequently are uneven- to broad-aged or have diameter distributions more closely associated with uneven-aged stands. Moreover, uneven-aged management may be more compatible or desirable for some management objectives or resource needs. For example, the impact on the forest should be as light as possible in areas of erosive soils, or where management goals include maintenance of continuous high forests.

Uneven-aged management includes cultural treatments, thinnings, and harvesting necessary to maintain continuous high forest cover, provide for regeneration of desirable species, either continuously or at each harvest, and provide for controlled growth and development of trees through the range of size classes needed for sustained yield of forest products. Managed uneven-aged stands are characterized by trees of many sizes and/or ages intermingled singly or in groups. Cutting methods do not produce stands of the same age that are large enough to be recognized as a stand. Forests are subdivided into recognizable units that can be located on the ground on the basis of timber type, site, logging requirements, etc., rather than acreage in stand-age classes. Regulation of young growing stock is accomplished by setting: (1) a residual stocking goal, in terms of basal area or volume, that must be maintained to provide adequate growth and yield, (2) a diameter distribution goal that will provide for regeneration, growth and development of replacement trees, and (3) a maximum tree size goal. In addition, a decision must be made on how to handle small trees.

Procedures described here are for entries into unregulated old-growth lodgepole pine, lodgepole pine-spruce-fir, or lodgepole pine—Douglas-fir stands that are to be converted to managed uneven-aged stands using either individual-tree or group selection cutting. It is not likely that unregulated stands will be brought under management with one entry or even a series of entries. It is more likely that limitations imposed by stand conditions, windfall risk, dwarf mistletoe, and mountain pine beetle susceptibility will result in either over- or under-cutting, at least in the first entry.

Individual Tree Selection Cutting

This regeneration cutting method harvests trees in several or all diameter classes on an individual basis. Stands regenerate continuously. The ultimate objective is to provide a stand with trees of different sizes and age classes intermingled on the same site (USDA Forest Service 1983). Choice of trees to be cut depends on their

Figure 32.—Schematic drawing of layout of skidroads and felling patterns.

characteristics and relationship to stand structure goals set up to regulate the cut. This cutting method provides maximum flexibility in choosing trees to cut or leave and is appropriate only in uniformly spaced stands with irregular to all-aged structure. However, because of lodgepole pine's silvical characteristics, individual-tree selection cutting is not recommended in pure stands. In mixed lodgepole pine-Engelmann spruce-subalpine fir or mixed lodgepole pine—Douglas-fir stands, individual trees selection can be used; but few pines are likely to become established after initial cutting.

Group Selection Cutting

This regeneration cutting method harvests trees in groups, ranging from a fraction of an acre up to about 2 acres (USDA Forest Service 1983). It is similar to a group shelterwood except in the way the growing stock is regulated. Trees are marked on an individual-tree basis; but emphasis is on group characteristics, which means trees with high potential for future growth are removed along with trees with low growth potential. Loss in flexibility is partly offset by the opportunity to uniformly release established regeneration and reduce future logging damage. When groups are composed of only a few trees, the method can be used together with individual-tree selection cutting in mixed stands. This cutting method is most appropriate in irregular to all-aged mixed or pure lodgepole pine stands that are clumpy or groupy. However, it can be used in uniformly spaced stands with the size, shape, and arrangement of openings based on factors other than the natural stand conditions (Alexander and Edminster 1977a, 1977b).

Stand Structure Goals

Control of Stocking

The first step in applying a selection cut to a lodgepole stand is to determine the residual stocking level to be retained. Because total stand growth for many species under uneven-aged management does not differ greatly over the range of stocking levels likely to be management goals, stocking levels set near the lower limit, where no growth is lost, concentrate increment on fewest stems. This reduces time required to grow individual trees to a specific size, and requires a minimum investment in growing stock (Alexander and Edminster 1977b).

The residual stocking level with the best growth in pure or mixed lodgepole pine stands varies with species composition, management objectives, productivity, diameter distribution, etc. In unregulated old-growth lodgepole pine stands with irregular structure, stocking usually varies from 100 to 200 square feet of basal area per acre in trees in the 4-inch and larger diameter classes. Basal areas above 150 to 160 square feet per acre probably represent overstocking. While no guidelines are available for uneven-aged stands, residual stocking levels of GSL 80 to GSL 160 are suggested for managed even-

aged stands, depending on site productivity, number of entries, and other management objectives (Alexander and Edminster 1981). These levels should be useful in estimating initial residual stocking goals in terms of square feet of basal area per acre for that part of the stand that eventually will be regulated under uneven-aged management (Alexander and Edminster 1977b).

While these general recommendation are probably adequate to start with, use of yield tables for even-aged stands in setting stocking goals for uneven-aged stands assumes there is little difference between the growing stock of the two, other than a redistribution of age classes over a smaller area (Bond 1952). This may be true when stands without a manageable understory of advanced growth are harvested by a group selection method. The result is likely to be a series of small, even-aged groups represented in the same proportion as a series of age classes in even-aged management. If advanced growth of smaller trees has become established under a canopy of larger trees, however, a different structure may develop with either individual-tree or group selection systems. Growing space occupied by each age or size class is being shared (Reynolds 1954). Assuming that damage to understory trees resulting from removal of part of the overstory trees can be minimized, advanced growth will successfully establish a series of age classes on some areas. In this situation, more trees of a larger size can be grown per acre than with a balanced even-aged growing stock (Bourne 1951, Meyer et al. 1961). Nevertheless, without better information, the residual stocking goals set for even-aged management are the best criteria available.

Maximum Tree Size

The second item of information needed is the maximum diameter of trees to be left after cutting. In old-growth lodgepole pine stands with irregular spacing, maximum diameter usually varies from 8 to 24 inches d.b.h., depending on stand density, site quality, species composition, etc. Examination of plot inventory information from unmanaged stands with irregular stand structure, suggests that a diameter of 18 inches can be attained within the time period generally considered reasonable under a wide range of site quality and stocking conditions. In the absence of any information on growth rates in uneven-aged stands, or rates of return for specific diameter and stocking classes, an 18-inch maximum diameter seems a reasonable first approximation to set for timber production. Trees of larger diameter with a lower rate of return on investment may be appropriate for multiple-use reasons (Alexander and Edminster 1977b).

Control of Diameter Distribution

Control over distribution of tree diameters also is necessary to regulate yields under uneven-aged management. This most important step is accomplished by

establishing the desired number of trees or basal area for each diameter class.

When used with flexibility, the quotient q between number of trees in successive diameter classes is a widely accepted means of calculating diameter distributions in uneven-aged stands (Meyer 1952). Values of q ranging between 1.3 and 2.0 (for 2-inch diameter classes) have been recommended for various situations. The lower the q, the smaller is the difference in number of trees between diameter classes. Stands maintained at a small q have a higher proportion of available growing stock in larger trees, for any residual stocking level, but may require periodic removal of the largest number of small trees in the diameter class where unregulated growing stock crosses the threshold into the proportion of the stand to be regulated (Alexander and Edminster 1977b).

Consider, for example, differences in numbers of small and large trees maintained at a q level of 1.1, 1.3, and 1.5 inches in stands with the same residual basal area (80 square feet) (table 1). At all stocking levels considered appropriate for future management goals, many small trees would have to be cut under lower q levels at the threshold diameter class (in this example the 4-inch class). Fewer larger trees would be retained under higher q levels.

In the absence of any experience, data, or good growth and yield information, the best estimate of numbers of trees to leave by diameter classes is to use the lowest q value that is reasonable in terms of existing markets, stand conditions, and funds available for cultural work. Examination of plot data from a wide range of irregularly stocked old-growth lodgepole pine stands indicates that pretreatment distributions are likely to range between 1.1 and 1.5 for 2-inch classes. As a general recommendation, q levels between 1.3 and 1.5 appear to be reasonable initial goals for the first entry into unmanaged stands, especially mixed stands (Alexander and Edminster 1977b).

How to Determine Residual Stand Structure

Once goals for residual stocking, maximum tree diameter, and q levels have been selected, the specific

structure for a stand can be calculated, provided that data are available to construct a stand table (Alexander and Edminster 1977b).

An existing old-growth lodgepole pine stand on the Fraser Experimental Forest in Colorado that was marked and cut as a demonstration is used to illustrate the procedure. The actual inventory data for the stand is shown in columns 1, 2, and 3 of table 2. A residual basal area of 80 square feet per acre in trees 4 inches d.b.h. and larger was chosen, because: (1) it allows maximum reduction (45%) in present basal area consistent with previously developed recommendations for minimizing blowdown after partial cutting (Alexander 1975), and (2) it is the lowest basal area that appears to be a realistic timber management goal in lodgepole pine stands. A maximum tree diameter of 18 inches d.b.h. was chosen, because it also appears to be a realistic goal to be attained in a reasonable period of time. Finally, a q of 1.3 was chosen, because it approximates the q in the natural stand, and does not require removal of many small trees. A lower q may be feasible, but it would require heavy cutting in lower diameter classes.

To determine the residual stand goal, the value of the residual density parameter k corresponding to a basal area of 80 square feet must be calculated. Values needed for this computation with a q of 1.3 are given in column 4 of table 3. The value of k is computed as

$$k = \frac{80.0}{1.09780 - 0.01678} = 74.0042$$

where 80.0 is the desired basal area per acre, 1.09780 is the table value for the desired maximum tree diameter class of 18 inches, and 0.01678 is the table value for the 2-inch class. Note that the value for the 2-inch class is subtracted from the 18-inch class value, because trees smaller than the 4-inch class are not considered in the management guidelines. Desired residual number of trees in each diameter class (columns 4 of table 2) can be directly calculated by multiplying the proper diameter class values given in column 4 of table 4 by the value of k. The desired residual basal area in each diameter class (column 5 of table 2) can be calculated by multiplying the residual number of trees in each diameter class by the tree basal area.

Table 1.—Residual stand structures for 80 square feet of basal area and maximum tree diameter of 18 inches d.b.h. for various q values.

Diameter class (inches)	q = 1.1		q = 1.3		q = 1.5	
	No. of trees	BA (ft.^{2})	No. of trees	BA (ft.^{2})	No. of trees	BA (ft.^{2})
4	20.86	2.03	42.85	3.74	75.28	6.57
6	18.94	3.72	33.74	6.62	50.16	9.84
8	17.23	6.02	25.91	9.04	33.90	11.83
10	14.98	8.17	19.98	10.90	22.31	12.17
12	14.23	11.18	15.37	12.07	14.90	11.70
14	12.84	13.73	11.81	12.66	9.92	10.61
16	11.77	16.43	9.08	12.68	6.61	9.22
18	10.70	18.91	6.98	12.33	4.41	8.07
Total	121.55	80.19	165.72	80.05	217.49	80.01

Table 2.—Actual stand conditions and management goals for a lodgepole pine stand. All data on a per acre basis—stand goals q = 1.3, residual basal area 80 square feet, maximum diameter of 18 inches d.b.h.

Diameter class (inches) (1)	Actual stand		Residual Stand Goal		Final Stand		Cut	
	Trees (2)	BA (ft.²) (3)	Trees (4)	BA (ft.²) (5)	Trees (6)	BA (ft.²) (7)	Trees (8)	BA (ft.²) (9)
4	158	13.79	58.16	5.08	58	5.06	100	8.73
5	74	10.09	44.74	6.10	45	6.14	29	3.95
6	55	10.80	34.41	6.76	34	6.67	21	4.13
7	46	12.30	26.47	7.08	26	6.95	20	5.35
8	26	9.08	20.36	7.11	20	6.98	6	2.10
9	29	12.81	15.66	6.92	16	7.07	13	5.74
10	19	10.36	12.05	6.57	12	6.55	7	3.81
11	19	12.54	9.27	6.12	9	5.94	11	7.26
12	22	17.28	7.13	5.60	8	6.28	14	11.00
13	15	13.83	5.48	5.06	7	6.45	8	7.38
14	7	7.48	4.22	4.51	5	5.34	2	2.14
15	6	7.36	3.22	3.95	5	6.14	1	1.22
16	4	5.58	2.50	3.49	2	2.79	2	2.79
17	1	1.58	1.92	3.03	1	1.58	0	0
18	0	0	1.48	2.61	0	0	0	0
Total	481	144.88	247.07	79.99	248	79.94	233	64.94

Table 3.—Values needed to compute k for different q ratios and diameter ranges using basal area as the density measure (Alexander and Edminster 1977b).

2-inch diameter classes (1)	q ratio									
	1.1 (2)	1.2 (3)	1.3 (4)	1.4 (5)	1.5 (6)	1.6 (7)	1.7 (8)	1.8 (9)	1.9 (10)	2.0 (11)
2	0.01983	0.01818	0.01678	0.01558	0.01454	0.01364	0.01283	0.01212	0.01148	0.01091
4	.09196	.07878	.06842	.06011	.05333	.04772	.04303	.03905	.03566	.03273
6	.23948	.19241	.15779	.13166	.11151	.09566	.08300	.07272	.06428	.05727
8	.47790	.36075	.28001	.22253	.18046	.14893	.12479	.10597	.09107	.07909
10	.81656	.57994	.42691	.32394	.25228	.20094	.16320	.13484	.11310	.09613
12	1.25990	84297	58963	42825	32124	24775	19574	15793	12979	10840
14	1.80848	1.14132	.75999	.52966	.38380	.28758	.22179	.17539	.14175	.11675
16	2.45985	1.46605	.93116	.62428	.43828	.32009	.24181	.18806	.14997	.12221
18	3.20930	1.80854	1.09780	.70981	.48425	.34580	.25671	.19697	.15545	.12566
20	4.05043	2.16089	1.25606	.78523	.52209	.36565	.26753	.20308	.15901	.12779
22	4.97568	2.51618	1.40336	.85042	.55251	.38065	.27524	.20719	.16127	.12908
24	5.97669	2.86853	1.53820	.90583	.57682	.39181	.28063	.20991	.16269	.12985
26	7.04470	3.21314	1.65994	.95229	.59576	.40000	.28435	.21168	.16357	.13030
28	8.17072	3.54619	1.76854	.99077	.61041	.40593	.28689	.21282	.16410	.13056
30	9.34585	3.86479	1.86444	1.02232	.62162	.41019	.28861	.21354	.16443	.13071
32	10.56133	4.16688	1.94837	1.04797	.63012	.41322	.28975	.21400	.16462	.13079
34	11.80875	4.45107	2.02126	1.06864	.63652	.41536	.29052	.21429	.16474	.13084
36	13.08011	4.71658	2.08412	1.08520	.64131	.41685	.29102	.21447	.16480	.13087

Table 4.—Values needed to compute desired number of residual trees for different q ratios (Alexander and Edminster 1977b).

2-inch diameter classes D_i (1)	q ratio									
	1.1 (2)	1.2 (3)	1.3 (4)	1.4 (5)	1.5 (6)	1.6 (7)	1.7 (8)	1.8 (9)	1.9 (10)	2.0 (11)
2	0.909091	0.833333	0.769231	0.714286	0.666667	0.625000	0.588235	0.555556	0.526316	0.500000
4	826446	694444	591716	510204	444444	390625	346021	308642	277008	250000
6	.751315	.578704	.455166	.364431	.296296	.244141	.203542	.171468	.145794	.125000
8	.683013	.482253	.350128	.260308	.197531	.152588	.119730	.095260	.076734	.062500
10	.620921	.401878	.269329	.185934	.131687	.095367	.070430	.052922	.040386	.031250
12	.564474	.334898	.207176	.132810	.087791	.059605	.041429	.029401	.021256	.015625
14	.513158	.279082	.159366	.094865	.058528	.037253	.024370	.016334	.011187	.007813
16	.466507	.232568	.122589	.067760	.039018	.023283	.014335	.009074	.005888	.003906
18	.424098	.193807	.094300	.048400	.026012	.014552	.008433	.005041	.003099	.001953
20	.385543	.161506	.072538	.034572	.017342	.009095	.004960	.002801	.001631	.000977
22	.350494	.134588	.055799	.024694	.011561	.005684	.002918	.001556	.000858	.000488
24	.318631	.112157	.042922	.017639	.007707	.003553	.001716	.000864	.000452	.000244
26	.289664	.093464	.033017	.012599	.005138	.002220	.001010	.000480	.000238	.000122
28	.263331	.077887	.025398	.008999	.003425	.001388	.000594	.000267	.000125	.000061
30	.239392	.064905	.019537	.006428	.002284	.000867	.000349	.000148	.000066	.000031
32	.217629	.054088	.015028	.004591	.001522	.000542	.000206	.000082	.000035	.000015
34	.197845	.045073	.011560	.003280	.001015	.000339	.000121	.000046	.000018	.000008
36	.179859	.037561	.008892	.002343	.000677	.000212	.000071	.000025	.000010	.000004

Comparing actual and desired diameter distributions shows where deficits and surpluses occur (fig. 33). To bring this stand under management, the number of trees should be allowed to increase in the diameter classes that are below the idealized stocking curve, with cutting limited to those diameter classes with surplus trees. As a guide, enough trees should be left above the curve in surplus diameter classes to balance the deficit in trees in diameter classes below the curve. In this example, all surplus trees were cut in the 4- to 11-inch diameter classes, while 1 to 2 surplus trees were left in the 12- to 15-inch classes to make up for deficits in the 16- to 18-inch classes. The final stand structure is shown in fig. 34 and columns 6 and 7 of table 2. Columns 8 and 9 show the trees and basal area removed (fig. 35).

Figure 34.—Actual stocking curve and recommended stocking curve based on stand structure goals and actual stand structure.

Figure 35.—Individual-tree selection cutting in a multistoried lodgepole pine stand, on the Fraser Experimental Forest based on figure 34.

How to Handle Small Trees

The threshold diameter class also must be determined. Calculations often are made down to the 4-inch diameter class by 2-inch classes, because often there are small trees, especially in mixed stands that are below minimum merchantable diameter. They compete with larger stems for growing space. More important, these trees provide
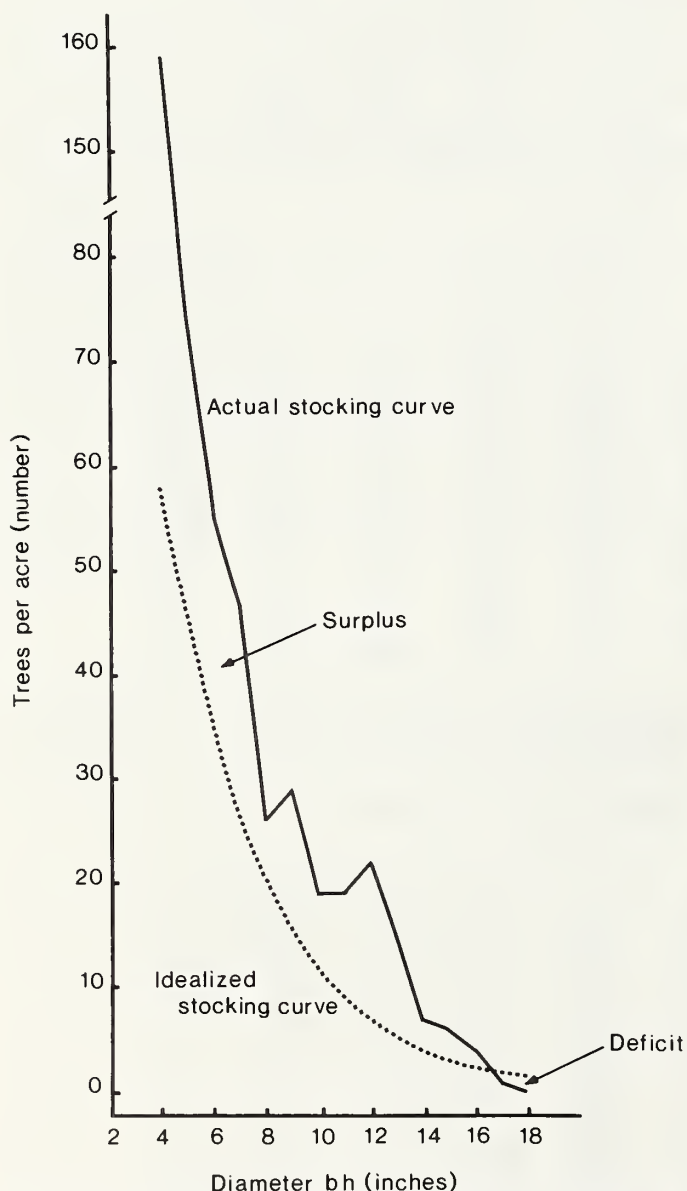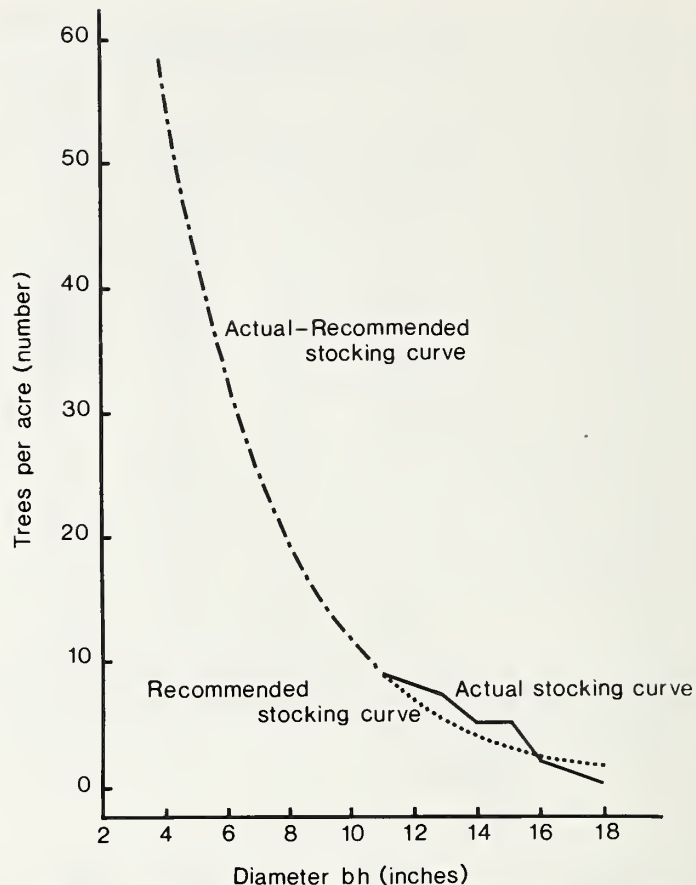
Figure 33.—Actual stocking curve from data collected on the Fraser Experimental Forest and the idealized stocking curve based on stand structure goals.

ingrowth into merchantable size classes needed to practice selection silviculture.

Although small trees should not be ignored in inventory and record keeping, it may be neither desirable nor possible to regulate the number of them. In lodgepole pine forests in the central Rocky Mountains, minimum merchantable diameter is usually 7 to 8 inches. Regulation of the number of trees below this size requires an investment in silvicultural work that may not be recaptured under current market conditions. However, if trees below minimum merchantable size are left unregulated, cutting must always be heavy in the threshold diameter classes to bring ingrowth trees down to the desired number. It also means that more growing space is required for small trees than called for by the idealized stand structure. Moreover, the higher the threshold diameter class, the greater is the proportion of the stand that is unregulated. More growing space is occupied by trees of low value that will be cut as soon as they cross the threshold diameter (Alexander and Edminster 1977b).

Marking Trees

After residual stocking goals have been calculated and a decision has been made on how to handle small trees, the stand must be marked. Marking is difficult, because the marker must designate cut or leave trees, usually with one pass through the stand, based on limited inventory data. At the same time, the marker must apply good silviculture and be aware of economic limitations. As a general rule, good silvicultural prescriptions are more important than strict adherence to structural goals, especially in unregulated stands being cut for the first time. However, marking without a structural goal—or prescribing structural goals that cannot be attained or applied—defeats the objective of regulation.

Because marking for individual-tree selection cutting is more complex than for other systems, some formal control procedure is necessary. Often, only an estimate of the initial desired residual diameter distribution is needed. With these estimates, basal areas and number of trees to be removed per acre by diameter classes can be determined. Control is maintained by a process of successive checks of residual versus the goal. For example, the markers should systematically make prism estimates of the residual stand after marking, recording trees by 2- or 4-inch classes on a standard cumulative tally sheet. Periodically, they should convert the prism tally to trees per acre, and compare their average prism estimate to the structural goal. Markers must then adjust to any serious deviation from the structural goal, such as too heavy marking in some diameter classes and too light in others. Their next check will determine if progress is being made or if further changes are needed. By this process, the average residual stand should come fairly close to the structural goal (Alexander and Edminster 1977b).

Marking under group selection cutting is less complex than under individual-tree selection; but control over the diameter distribution also is necessary. The objective is to create a series of openings with each opening containing a given diameter class.

Recommendations for Selection Cutting

These are based on experience, windfall risk, and dwarf mistletoe and mountain pine beetle susceptibility. Selection cutting methods are appropriate for three- and multi-storied pure or mixed stands with irregular or uneven-age stand structure. Individual-tree selection should be confined to mixed stands with uniform spacing. Group selection can be used in stands with either clumpy-groupy spacing or uniform spacing. Selection cutting methods are not appropriate in high wind risk situations, in stands sustaining a mountain pine beetle attack, or in stands where enough beetles are present within the stand or adjacent stands to make fatal attacks, or in stands where the dwarf mistletoe rating is 3 or more.

Stand Structure Goals, Cutting Treatments, and Reentry Schedules

In low wind risk situations, not more than 30% to 40% of the stand basal area should be removed. With individual tree selection, the cut should be distributed over the entire area. With group selection, not more than one-third of area should be cut. If the stand is clumpy, the size of opening should be determined by the size of the clump. If the stand is uniformly spaced, the size of the opening should not exceed two times tree height. In above average wind risk situations, not more than 20% to 30% of the stand basal area is removed. Distribute the cut over the entire area with individual-tree selection. Not more than one-fourth of the area should be cut with group selection. Keep the openings small. If the stand is clumpy, the opening should be no larger than the size of the clump. If the stand is uniformly spaced, openings should not exceed one times tree height.

Maximum tree diameter should not exceed that attained in the unmanaged stand. The diameter distribution should be set at a "q" value that most closely approximates the natural "q" value of the stand. However, remember that low q values require cutting a larger number of trees at the threshold diameter class and high q values retain few larger trees. The threshold value should be set at the smallest diameter class practical. All trees below the threshold diameter class are unregulated. Some diameter classes will have a surplus of trees and some will have a deficit. Surpluses and deficits must be balanced if the residual basal area is to be maintained.

Subsequent entries should be made at 10- to 30-year intervals. While it would be desirable to enter the stand at 10-year intervals, it is not likely that this will be possible in most instances. Some diameter classes will not be completely represented; therefore, volumes available for cutting may not warrant a 10-year reentry until a controlled diameter distribution is attained.

Protecting the Residual Stand

Protection of the residual stand is critical with individual-tree selection cutting because of frequent entries into the stand once a controlled diameter distribution is attained. Damage can result from felling, skidding, and slash disposal.

Felling damage can be reduced by using group selection and dropping trees in the openings, or marking a small clump of trees where felling one large tree will damage several adjacent trees. Procedures outlined for protecting the residual and disposing of slash for shelterwood cutting should be followed here.

COST OF SALE ADMINISTRATION AND LOGGING

Costs are important in harvesting lodgepole pine stands, because values have been low to moderate, and logging is difficult on steep terrain. One of the most important factors affecting the administrative cost of selling timber is the number of entries needed for harvesting. Clearcutting and simulated shelterwood require only one entry. Standard shelterwood requires two to three entries, while group shelterwood, individual-tree and group selection require from three to six entries, depending upon cutting cycles. In managed stands, even-aged systems require a minimum of two additional entries for thinnings; but the number of entries under uneven-aged systems would not change.

Costs of sale layout, marking, and sale contract administration are lower for clearcutting, simulated and group shelterwood, group selection (when groups are near the maximum size), and the final cut of standard shelterwood than for individual tree selection, and the intermediate, preparatory, and seed cuts of standard shelterwood. Costs are reduced, because only cutting boundaries are marked, and no time is spent marking trees to cut or leave. Sale administration is easier, because there are no residual trees to protect and no opportunity to cut unmarked trees. However, reproduction must be protected at the time of final cut under any shelterwood system. Costs for selection methods are further increased, because highly skilled individuals are required to recognize, mark, and protect trees that needed to be left to obtain the regulated distribution of diameter classes.

Timber harvesting usually requires road construction. Clearcutting is the most economical method in terms of volume removed per unit of road, while individual-tree selection is the most expensive. Development of a transportation system to manage forests is a costly front-end investment that will require funding in addition to the value of stumpage at the time of first entry. Once the transportation system has been constructed, road costs should be independent of cutting method.

In addition to producing maximum volume per acre in one operation, clearcutting permits the greatest flexibility in selection of logging equipment and minimum concern for protection of residual trees. The first entry of a standard shelterwood is intermediate in volume production per acre, requires moderate concern for the residual stand, and places some constraints on selection of equipment. The final cut of a standard shelterwood or simulated shelterwood has the advantages of clearcutting, except for the need to protect the new stand. Individual-tree selection requires maximum concern for the residual stand. Group selection and group shelterwood require slightly less if the size of the opening is near maximum. Under uneven-aged and group shelterwood cutting methods, volumes per entry are intermediate, size-class diversity of products harvested is maximum, and a choice of logging equipment is restricted to smaller or specialized machines.

MULTIPLE-USE SILVICULTURE

POTENTIAL TIMBER YIELDS

Highest potential timber yields can be realized under a clearcutting or a two-cut shelterwood option, provided that the final harvest with a shelterwood is made within 5 years after regeneration is established. Comparable growth rates can be achieved with group shelterwood and group selection only if the openings are near the maximum size (2 acres). Total yields will be less under a three-cut shelterwood. Under simulated shelterwood, yield increases resulting from reduction in rotation length will be offset by the slower growth of tolerant species in the replacement stand. Yields will be considerably less under individual-tree and group selection in situations where lodgepole pine is difficult to maintain and very small openings are cut (Alexander et al. 1983).

SOIL WATER RESOURCES

Water Yield

In high elevation lodgepole pine forests, the proportion of water yielded to precipitation is high because of the cold climate, short growing season, and accumulation of overwinter snowpack. Approximately 90% of the water available for streamflow comes from snowmelt. The most efficient timber harvest pattern for increasing water yield (2 + inches) in old-growth forests is to clearcut about 30% to 40% of a drainage in small, irregular-shaped patches about five to eight times tree height in diameter (3 to 5 acres), interspersed with uncut patches of about the same size and shape (fig. 36) (Leaf 1975; Leaf and Alexander 1975; Troendle 1982, 1983a, 1983b; Troendle and Leaf 1981). With this pattern, wind movement across the canopy is changed so that more snow accumulates in the openings than under adjacent stands.

Total snowfall in the drainage may or may not be increased by cutting, depending upon aspect (Hoover and Leaf 1967, Troendle and Meiman 1984); but melt occurs earlier and at an increased rate in the openings, causing the rising limb of the hydrograph to occur earlier than timber harvest. Most of the increase in flow comes during the period before the peak, which may be somewhat higher; but recession flows are about the same as before harvest.

Increase in streamflow is not likely to significantly diminish for 20 to 30 years, and treatment effect will not disappear until the new stand in the openings is tall enough to change the snow accumulation pattern. At that time, a number of alternatives can be considered. (1) Recut the original openings. The remaining area would be retained as continuous high forest; trees would be harvested periodically on an individual-tree basis. Ultimately, the reserve stand would approach an all-aged structure with the overstory canopy remaining at about the same height, although the original overstory could not be maintained indefinitely. (2) Make a light cut distributed over the entire watershed, removing about 20% to 30% of the basal area on an individual-tree basis or in small groups. The objective would be to open up the stand enough to develop windfirmness, and salvage low-vigor and poor-risk trees. Openings five to eight times tree height can then be cut on about one-third of the area. The remaining two-thirds of the area would be retained as permanent high forest, with trees periodically removed on an individual-tree basis or in small groups. (3) Another alternative that would integrate water and timber production would be to harvest all of the old-growth in a cutting block in a series of cuts spread over 100 to 120 years. Each cutting block would contain at least 300 acres, subdivided into circular or irregular-shaped units approximately 2 acres in size or four to five times (in diameter) the height of the general canopy level. At periodic intervals, some of these units, distributed over the cutting block, would be harvested and the openings would be regenerated. The interval between cuttings could vary from as often as every 10 years to as infrequently as every 30 to 40 years. The percentage of units cut at each interval would be determined by cutting cycle/rotation age × 100. At the end of one rotation, each cutting block would be composed of groups of trees in several age classes ranging from reproduction to trees ready for harvest. The tallest trees would be somewhat shorter than the original overstory; but any adverse effect on snow deposition should be minimized by keeping the openings small and widely spaced (Alexander 1974).

Figure 36.—Three-acre openings cut to increase streamflow, south-slope lodgepole pine, on the Fraser Experimental Forest.

Cutting openings larger than 5 acres may be less efficient in increasing streamflow because as opening size increases, wind can scour deposited snow causing it to evaporate into the air or blow into adjacent stands where recharge requirements and evapotranspiration are greater. However, these larger openings can be managed to minimize wind scour and maintain snowpack on the site. By leaving residual stems standing and moderately heavy slash in place to provide roughness to hold snow, 20% to 30% more water can be retained in the snowpack than in the uncut forest even in relatively large openings (Troendle and Meiman 1984).

Group selection and group shelterwood cutting can be nearly as favorable for water production as patch clearcutting, if openings are near the maximum size of 2 acres. Increase in water available for streamflow under individual-tree selection will be less than cutting small openings but still significantly higher than in the uncut forest. Canopy reduction by removing trees on an individual basis results in less interception of snow and subsequent evaporation from the canopy. This combined with any other reduction in consumptive use (ET) can result in greater streamflow (Troendle and Meiman 1984).

Standard shelterwood results in increases similar to individual-tree selection as long as an overstory remains. After final harvest under any standard shelterwood alternative, water available for streamflow will increase to the level obtained under patch clearcutting, provided that the area cut is similar in size and arrangement to openings recommended for patch clearcutting. The interval of increased water yield will be proportional to time required for the replacement stand to grow tall enough to modify wind movement across the canopy.

Soil Erosion and Water Quality

Soil and site conditions are not the same in all lodgepole pine forests; but the careful location, construction, and maintenance of skid and haul roads associated with any silvicultural system should not cause a lasting increase in sedimentation. For example, on the Fool Creek drainage in central Colorado, where about 12 miles of main and secondary roads were constructed to remove timber in alternate clearcut strip from about one-third of the drainage, annual sediment yields during road construction and logging were only about 200 pounds per acre (Leaf 1970), and decreased rapidly after logging, despite a persistent increase in runoff. Annual sediment yields after logging have averaged about 43 pounds per acre, compared to 11 to 31 pounds from undisturbed watersheds (Leaf 1975).

Nutrient Losses and Stream Water Temperature Changes

Removal of logs in timber harvest represents a small and temporary net loss of nutrients, because only a minor proportion of the nutrients taken up by a tree is stored in the bole. Clearcutting results in a greater immediate

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loss than individual-tree selection; but over a similar time frame, the losses would balance out because of more frequent cuts under the selection system. Furthermore, nutrients lost after clearcutting should be replaced in 10 to 20 years through natural cycling as regeneration becomes established.

Comparison of streamflow from logged and unlogged subalpine watersheds in central Colorado provided some indication of effect on chemical water quality. Ten years after clearcutting, cation concentration during a 10-week period was 1.8 ppm greater and cation outflow 5.2 pounds per acre per year greater on the logged watershed (Stottlemeyer and Ralston 1968).

Increases in stream temperature can be avoided, even with clearcutting, by retaining a border of trees along stream channels. Actually, clearcutting to the stream channel and subsequent warming of the water may be advantageous where streams are small and too cold to support adequate food supplies for fish.

WILDLIFE AND RANGE RESOURCES

Game Habitat

Biotic diversity is generally low in old-growth lodgepole pine stands; but these forests provide habitat for a variety of game. Clearcutting, group shelterwood, and group selection provide the largest increases in quantity and quality of forage for big game; but use often is limited by the amount of cover available for hiding, resting, and ruminating. Furthermore, game populations are not directly related to forage availability on summer ranges, because carrying capacity of winter ranges limits the number of animals. Mature unlogged lodgepole pine stands in Colorado produce enough forage to support more mule deer than are presently estimated to occupy summer ranges (Regelin et al. 1974).

Dispersed openings 2 to 20 acres in size are used more by deer and elk than smaller or larger openings or uncut timber (Regelin and Wallmo 1978, Wallmo 1969, Wallmo et al. 1972). Small openings provide little diversity, and overly large openings (more than 40 acres) radically alter in habitat, especially if they are coupled with extensive site preparation and tree planting. As trees grow to seedling and sapling size, forage production in cleared areas diminished (Basile and Jensen 1971, Wallmo et al. 1972); but cover increases until it reaches maximum in mature stands. Because natural succession is likely to replace the more palatable forage species with tree reproduction in 15 to 20 years (Regelin and Wallmo 1978), a more desirable alternative would be to cut new openings periodically while allowing the older cuttings to regenerate. That would provide a constant source of palatable forage and the edge effect desired. The openings created should be widely spaced, with stands between openings maintained as high forest.

One alternative that would integrate wildlife habitat improvement with timber production would be to cut about one-sixth of a cutting block every 20 years in openings about four to five times tree height. Each working circle would be subdivided into a number of cutting blocks (of at least 300 acres) so that not all periodic cuts would be made in a single year on a working circle. Such periodic cutting would provide a good combination of numbers and species of palatable forage plants and the edge effect desired, while creating a several-aged forest of even-aged groups (Alexander 1974).

Observations on the Medicine Bow National Forest in Wyoming indicate that both natural and cleared openings in lodgepole pine forests are heavily used by elk for grazing and calving. The size of opening does not appear to be critical; but openings interspersed with standing timber that can be used for ruminating, resting, and hiding are preferred. Because openings cut in the canopy are not likely to retain a high proportion of palatable forage species for long periods of time, new openings should be cut while allowing the older ones to regenerate (Alexander 1974).

Standard shelterwood cutting provides less forage for big game than cutting methods that create openings; and the reduction is in proportion to the density of the overstory and length of time it is retained. Shelterwood cutting also provides less cover than an uncut forest. Individual-tree selection provides forage and cover comparable to uncut forests, thus maintaining one type of habitat at the expense of creating diversity.

Game animals other than deer or elk also are influenced by the way forests are managed. For example, with the decrease in wildfires, some reduction in stand density of logging may be necessary to create or maintain drumming grounds for male blue grouse. Standard shelterwood, group shelterwood, or group selection cutting that opens up the stand enough to allow regeneration to establish in thickets provides desirable cover. Small, dispersed clearcuts (5 to 10 acres) also are favorable if thickets of new reproduction become established (Martinka 1972).

Nongame Habitat

Little information is available on the relationship of cutting methods in lodgepole pine forests to specific nongame habitat requirements; but it is possible to estimate probable effects. Clearcutting, group shelterwood, and group selection that create small, dispersed openings provide a wide range of habitats attractive to some birds and small mammals by increasing the amount of nontree vegetation—at least initially—and length of edge between dissimilar vegetation types. On the Fool Creek watershed, for example, where 40% of the timber was cleared in alternate strips one to six chains wide, many species of birds feed in openings and nest in trees along the edge. In contrast, only woodpeckers and sapsuckers have been observed in adjacent uncut stands (Myers and Morris 1975).

However, Scott et al. (1982) compared numbers and species of nongame birds on two 100-acre subdrainages on Deadhorse Creek, in the Fraser Experimental Forest. One-third of one subdrainage was clearcut in 3-acre patches; the other was left uncut. They found that total numbers of birds did not significantly change with cutting. However, there was a small postharvest decline in

the "foliage nesting" and "picker" and "gleaner" feeding guilds. There were no significant changes in small mammal populations after timber harvest. Lodgepole pine forests commonly occur as a long-lived seral on spruce-fir habitat types. Clearcutting can maintain lodgepole pine on these sites, thereby maintaining a diversity of cover types that is desirable for a variety of nongame wildlife.

Standard shelterwood cutting provides a variety of habitats attractive to species that forage in stands with widely spaced trees, but not to those that require closed forests or fully open plant communities. Under this method, trees are still available for nesting, denning, and feeding until the final harvest, when consideration should be given to retaining some of the snags and live trees with cavities. To insure future cavities, Scott et al. (1978) recommended leaving all broken-top snags greater than 8 inches d.b.h. and live trees with broken tops or scars.

Harvesting old-growth timber can be devastating to species that nest or den in snags and in cavities of live trees, feed largely on tree seeds, or require solitary habitats normally associated with large areas of old-growth. Most nongame species have a minimum habitat size below which they can not exist. Small patches of varying ages and structure and all-aged stands may reduce the number of species (Alexander et al. 1983). Individual-tree selection provides the least horizontal diversity, and favors species attracted to uncut forests or that require vertical diversity. However, snags and live tree cavities can be retained under any silvicultural system.

Livestock Grazing

Understory vegetation in lodgepole pine forests is potentially important as forage for big game and livestock; but production varies widely. In dense stands, there is little or no understory vegetation. As the overstory decreases, forage production increases, reaching maximum in recently clearcut openings or burns. Forage production, changes in species composition, and palatability vary considerably, depending upon the plant community and successional stage. The increase in forage production in openings usually persists for about 10 to 20 years before competition from tree reproduction begins to reduce understory vigor and composition. It can be maintained only by frequent thinnings and intermediate cuts that keep growing stock levels low (Alexander et al. 1983).

RECREATION AND ESTHETICS

Lodgepole pine forests provide a variety of recreation opportunities. Users who hike, backpack, ski, tour, or view scenery are generally attracted to forests whose natural appearance is little altered by human activities (Calvin 1972). In contrast, hunters have best success where human activities are apparent—timber sales and other areas readily accessible by roads. Fishing is mostly done in accessible lakes, reservoirs, and streams.

Generally, most camping opportunities are at both publicly and privately developed sites served by roads. Most scenery viewing is by automobile on developed roads. Moreover, most of the winter use of snowmobiles for recreation in lodgepole pine forests is on roads. Finally, some forms of recreation, such as downhill skiing and mountain home development, require drastic modification of the natural forest landscape.

Clearcutting has the greatest visual impact and individual-tree selection has the least. However, variety typical of forests at the highest elevations—whose texture is broken by natural openings—is preferred to the monotony of vast, unbroken forest landscapes at middle and lower elevations (Kaplan 1973).

To enhance amenity values, openings cut for timber and water production and wildlife habitat improvement should be a repetition of natural shapes, visually tied together to create a balanced and unified pattern that will complement the landscape (Barnes 1971). This is especially important for openings in the middleground and background seen from a distance. Standard or simulated shelterwood, or individual-tree selection can be used to retain a landscape in foregrounds. Well planned clearcut openings also can be used to create vistas along well traveled road systems.

Individual-tree selection, group selection, and group shelterwood cutting are appropriate in high-use recreation areas, travel influence zones, scenic-view areas, and lands adjacent to ski runs—and also near support facilities and subdivision developments where permanent forest cover is desired. The visual impact of logging can be minimized by cleanup of debris and slash and by careful location of roads (Alexander et al. 1983).

COMPARISON OF CUTTING METHODS

No silvicultural system or cutting method (including no cutting at all) meets all resource needs. Cutting small openings provides maximum yields of timber at minimum costs, promotes the largest increases in water production without serious reduction in quality, produces diversity in food supply and cover favored by many wildlife species, and is necessary for the development of recreation sites for skiing and home subdivisions. Production and utilization of livestock forage are less than on larger openings, while clearcutting in any form destroys the habitat of wildlife species that dwell in closed forests. Clearcutting can create adverse visual effects if no thought is given to the size and arrangement of the openings; but it can also be used to create landscape variety that will enhance amenity values.

Standard and simulated shelterwood cutting also provide maximum timber yields over the same time interval, but at increased costs; they produce a wide range of wildlife habitats, but with less forage than openings and less cover than uncut forests. Water yields are increased over natural streamflow but less than with clearcutting small openings. Shelterwood cutting provides a partial retention of the forest landscape, but only when the overstory is retained for a long time.

Group selection and group shelterwood cutting, with the size of opening near the maximum, favor and discriminate against the same resource values as patch or strip clearcutting. They are more expensive and less flexible, however. Individual-tree selection cutting is not appropriate for timber production in pure lodgepole pine stands but could be used to meet other resource needs. Water yields are greater than from uncut forests. Individual-tree selection cutting provides minimum horizontal diversity in wildlife habitat, but favors species attracted to uncut forests. It also provides maximum partial retention of the natural forest landscape. Group selection with very small openings accomplishes about the same things as individual-tree selection.

Not all resource needs can be met on a given site, nor is any one cutting method compatible with all uses. Land managers must recognize the potential multiple-use values of each area, determine the primary and secondary uses, and then select the management alternative that is most likely to enhance or protect these values. On an individual site, some uses probably must be sacrificed or diminished to maintain the quantity and quality of others.

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Guidelines are provided to help forest managers and silviculturists develop even- and/or uneven-aged cutting practices needed to convert old-growth and mixed lodgepole forests into managed stands. Guidelines consider stand conditions, succession, windfall risk, and insect and disease susceptibility. Cutting practices—clearcutting, shelterwood, and selection—are designed to integrate timber production with increased water yield, maintain water quality, improved wildlife habitat, and enhanced opportunities for recreation and scenic beauty.

Keywords: Silvicultural systems, timber harvesting, forest management, *Pinus contorta*

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U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

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Southwest

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The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

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Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

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Flagstaff, Arizona
Fort Collins, Colorado*
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Lincoln, Nebraska
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